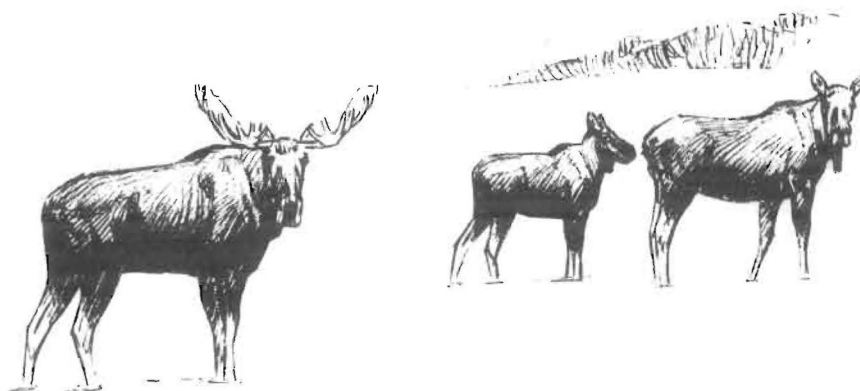




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Estimating moose population parameters from aerial surveys

*William C. Gasaway, Stephen D. DuBois,
Daniel J. Reed, and Samuel J. Harbo*



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**ESTIMATING MOOSE POPULATION PARAMETERS
FROM AERIAL SURVEYS**

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PREFACE

Successful moose management depends on knowledge of population dynamics. The principal population parameters required are size, rate of change, recruitment, sex composition, and mortality. Moose management in Alaska has been severely hampered by the lack of good estimates of these parameters, and unfortunately, this lack contributed to the decline of many Alaskan moose populations during the 1970s (e.g., Gasaway et al. 1983). The problems were: (1) population size was not adequately estimated, (2) rapid rates of decline were not acknowledged until populations were low, (3) meaningful recruitment rates were not available in the absence of good population estimates, and (4) calf and adult mortality rates were grossly underestimated.

Frustration of moose managers working with inadequate data led to the development of aerial survey procedures that yield minimally biased, sufficiently precise estimates of population parameters for most Alaskan moose management and research. This manual describes these procedures.

Development of these procedures would have been impossible without the inspiration, support, advice, and criticism of many colleagues. We thank these colleagues for their contributions. Dale Haggstrom and Dave Kelleyhouse helped develop flight patterns, tested and improved early sampling designs, and as moose managers, put these procedures into routine use. Pilots Bill Lentsch and Pete Haggland were instrumental in developing and testing aerial survey techniques. Their interest in and dedication to improving moose management made them valuable allies. Statisticians Dana Thomas of the University of Alaska and W. Scott Overton of Oregon State University provided advice on variance approximations for the population estimator. Warren Ballard, Sterling Miller, SuzAnne Miller, Doug Larsen, and Wayne Kale tested procedures and provided valuable criticisms and suggestions. Jim Raymond initially programmed a portable calculator to make lengthy calculations simple, fast, and error-free. Angie Babcock, Lisa Ingalls, Vicky Leffingwell, and Laura McManus patiently typed several versions of this manual. John Coady and Oliver Burris provided continuous moral and financial support for a 3-year project that lasted 6 years. Joann Barnett, Rodney Boertje, Steven Peterson, and Wayne Regelin of the Alaska Department of Fish and Game provided helpful editorial suggestions on previous drafts. Finally, we thank referees David Anderson of the Utah Cooperative Wildlife Research Unit, Vincent Schultz of Washington State University, and James Peek, E. "Oz" Garton, and Mike Samuel of the University of Idaho whose comments and suggestions improved this manual. This project was funded by the Alaska Department of Fish and Game through Federal Aid in Wildlife Restoration Projects W-17-9 through W-22-1.

1. INTRODUCTION

This is an instruction manual and field guide for estimating population parameters for moose in the circumpolar northern boreal forest, the subalpine zone, and the north-coastal shrub zone. Depending on the density of forest canopies in other areas, these methods may require some modifications or may not be usable. The manual is detailed and designed for field personnel. We describe one set of the many ways to estimate moose population parameters. We do not argue the pros and cons of the various methods available; however, we considered many options while developing the procedures in this manual and selected the ones best suited for our purposes. For alternatives to these techniques, we refer you to some of the many manuals and publications on estimating population parameters (e.g., Bergerud and Manuel 1969; Jolly 1969; Caughley and Goddard 1972; Caughley 1974, 1977; Croskery 1975; Caughley et al. 1976; Eberhardt 1978; Norton-Griffiths 1978; Cook and Jacobson 1979; Crête 1979; Thompson 1979; Burnham et al. 1980; Seber 1982; White et al. 1982; Gasaway and DuBois 1987).

Moose population parameters discussed in this manual are: (1) size; (2) rate of change; (3) sex and age composition and recruitment; and (4) distribution, i.e., spatial relative abundance. Mortality, the remaining important population parameter, is not addressed here, but it can be estimated indirectly from the four discussed parameters (Bergerud 1978, 1980). Population size is the most difficult of the four parameters to estimate. Given the method for estimating population size, methods for estimating other parameters follow easily. Therefore, estimating population size is a central part of this manual. For brevity, we use the term population estimate to specify an estimate of population size, i.e., number of moose in the population.

Estimating moose population size has always been a problem (Timmermann 1974), yet good estimates are essential for managers to understand population dynamics. In our view, methods for estimating population size must meet five criteria: (1) be unbiased, i.e., on the average not over- or underestimating actual population size; (2) provide an adequate level of precision (as indicated by the width of the confidence interval) based on realistic measures of major sampling errors; (3) be suitable for flat, hilly, and mountainous terrain; (4) not require special maps or aerial photos for sampling; and (5) be affordable.

Our method of estimating population size, based on a stratified random sampling design modified from Siniff and Skoog (1964) and Evans et al. (1966), satisfies these five criteria as follows: (1) bias is minimized by using flight patterns and search efforts that provide high sightability (percentage animals seen) of moose and by estimating a good sightability correction factor (SCF) for moose not seen, (2) estimates of precision combine both sampling variance of estimated observable moose and sampling variance

of the estimated SCF, (3) suitability in all types of terrain is achieved by using irregularly shaped sample units (SU) and varying search patterns, and (4) special maps or photos are avoided by using natural terrain features on conventional topographic maps for SU boundaries.

Estimates of the remaining population parameters rely on data obtained from either surveys to estimate population size or separate application of portions of that survey method. Rate of population increase or decline is determined from a comparison of population estimates separated by one or more years. Estimates of sex composition and recruitment, obtained during population estimation surveys, contain little bias because of high sightability of moose and random sampling. Distribution, i.e., spatial relative abundance, is obtained by using the stratification process of the population estimation survey.

When precise and nearly unbiased methods for estimating population parameters become routine, new horizons will open for wildlife biologists. The effects of new management programs, habitat changes, severe winter weather, and predator-prey relationships can be evaluated with estimates of rate of population change. Harvest quotas and numbers of moose killed by hunters and predators can be more easily interpreted with good estimates of numbers of moose in sex-age classes. Numbers of moose killed can be compared to standing stock in sex-age classes, and rates of harvest can be estimated subsequently. Recruitment can be weighed against independent estimates of mortality to achieve a rapid assessment of population status and likely population trend. With a better grasp of the dynamics of a moose population, management options become more apparent. Portions of this manual are specific to estimating moose population parameters, e.g., population size; however, the concepts used can be applied to other species. Other estimation procedures in this manual, e.g., rate of population change, are more general and apply directly to many species.

Many of the formulas presented in this manual will be new to the reader. A statistician adept at sampling theory and methods will note that some are not quite appropriate theoretically due to violations of assumptions and that many formulas have a form of computation bias known as small-sample bias. We have been aware of these problems. Unfortunately, sampling theory offers no reliable, unbiased, computationally efficient formulas for many of the parameter estimates that we needed. In the statistical sense, the formulas we recommend are approximations. The formulas have been tested using computer simulation techniques and are reliable if the recommendations on methodology are followed.

This manual is a step-by-step field guide for conducting surveys and estimating population parameters. Although the manual is intended to be self-explanatory, we recommend that prior to conducting a population estimation survey all

participants attend a workshop conducted by a person experienced with the technique. Examples of calculations are given to ensure correct treatment of data. To expedite calculations and reduce errors, programs have been written for the Hewlett-Packard 97 calculator (HP 97) to calculate optimal allocation of sampling effort, estimates of moose abundance, estimates of sex and age composition, and confidence intervals for all estimates. Upon request, we will supply copies of the programs on magnetic cards, or you may program the HP 97 directly from the program listings in Appendix 1. With minor changes, these programs can be adapted for the Hewlett-Packard 41C calculator. At the time of this printing, a program to perform these calculations is in development for IBM PC and compatible computers. Contact the authors for availability of the program. Sample forms are provided for recording observations and storing results. These forms may be photo-copied and used directly

or modified to meet individual needs. The glossary defines abbreviations used in this manual.

Suggested reading in this manual varies with a person's involvement in estimating population parameters. Field staff involved only in aerial surveys should read Sections 2, 3.1 to 3.4, 3.5.2, 3.6.1 to 3.6.5.2, 3.6.6, and 6. Persons in charge of surveys and who calculate estimates of population parameters with a preprogrammed HP 97 should read all Sections except 3.8, 5.3, and 5.6. Persons in charge of surveys, but who calculate estimates of population parameters without a preprogrammed calculator, should read all Sections except 3.9, 3.11, 5.4, and 5.7.

Finally, if our descriptions of methods are unclear, feel free to contact us for clarification. Our phone numbers are (907) 456-5156 or 452-1531, and our address is ADF&G, 1300 College Road, Fairbanks, Alaska 99701.

2. REVIEW OF SAMPLING ERROR AND PRECISION

A review of sampling error and precision of estimates will be helpful before describing the methods of estimating population parameters. First, we define some commonly used terms. A population is a collection or set of individuals or objects whose properties are to be analyzed, e.g., all SUs in a survey area or moose in an area. A parameter is a numerical characteristic of an entire population. A sample is a subset of a population, and, typically, a random sample is one in which every element in the population has an equal probability of being chosen as part of the sample. For additional reading on sampling and precision estimation see White et al. (1982), Simpson et al. (1960), Stuart (1984), and Scheaffer et al. (1979).

A population parameter (e.g., density of moose) estimated from a random sample usually differs from the actual population parameter. This difference is a result of each SU differing in density from that of the overall density in the survey area; therefore, mean density in a sample of n SUs is a function of which SUs were selected. The mean of a second random sample would be expected to differ from the first as well as from the actual parameter by a random amount. The difference between the estimated value from one set of observations and the actual value is the sampling error.

We can use a general formula for calculating moose population size to demonstrate where sampling error enters population estimates. The actual number of moose is calculated as

$$\text{actual number of moose} = \text{actual density} \times \text{area}.$$

Although actual density cannot be determined, it can be estimated as

$$\begin{array}{ccccc} \text{estimated} & & \text{estimated} & & \text{estimated} \\ \text{moose} & = & \text{observable} & \times & \text{correction factor} \\ \text{density} & & \text{moose density} & & \text{for missed moose.} \end{array}$$

The correction factor for missed moose corrects for sightability bias. Substituting estimated density for actual density in the above formula, we get

$$\begin{array}{ccccc} \text{estimated} & & \text{estimated} & & \text{estimated} \\ \text{number of} & = & \text{observable} & \times & \text{correction factor} \\ \text{moose} & & \text{moose density} & & \text{for missed moose} \end{array} \times \text{area}.$$

Because each estimate has a random sampling error associated with it, the above formula can be rewritten to include these sampling errors, where area is measured without error.

$$\begin{array}{ccccccc} \text{Actual} & & \text{estimated} & & \text{estimated} & & \text{estimated} \\ \text{number} & = & \text{number of} & = & \text{observable} & \times & \text{correction} \\ \text{of moose} & & \text{moose} + \epsilon_1 & & \text{moose} & & \text{factor} \\ & & & & \text{density} & & \text{for missed} \\ & & & & + \epsilon_2 & & \text{moose} \\ & & & & & & + \epsilon_3 \end{array} \times \text{area}$$

where ϵ_i = the random sampling error for the i th estimate ($i = 1, 2, 3$). In this formula, the sampling error of the esti-

mated number of moose, ϵ_1 is affected by sampling errors associated with both density and missed moose, ϵ_2 and ϵ_3 , respectively.

Now, let us look at an example of how variation in sampling error associated with moose density estimates affects population estimates. For the time being, assume 100% of the moose were seen in each SU searched, so that the estimate of missed moose drops out of the density equation. Figure 1 shows the fictitious Square Mountain survey area

1	2	3	4	5	6	7	MOOSE POPULATION ESTIMATES
0	1	1	3	4	4	1	
8	9	10	11	12	13	14	840
9	3	11	7	2	9	3	805
15	3	10	1	12	3	6	742
16	10	1	12	3	6	12	788
22	6	11	13	22	13	35	801
23	6	11	13	22	13	35	624
24	6	11	13	22	13	35	714
25	3	36	23	67	24	15	677
26	3	36	23	67	24	15	733
27	3	36	23	67	24	15	879
28	3	36	23	67	24	15	$\mu = 763$
29	3	36	23	67	24	15	
30	3	36	23	67	24	15	
31	3	36	23	67	24	15	
32	3	36	23	67	24	15	
33	3	36	23	67	24	15	
34	3	36	23	67	24	15	
35	3	36	23	67	24	15	
36	12	1	17	57	49	14	
37	12	1	17	57	49	14	
38	12	1	17	57	49	14	
39	12	1	17	57	49	14	
40	12	1	17	57	49	14	
41	12	1	17	57	49	14	
42	12	1	17	57	49	14	
43	13	19	20	32	2	3	
44	13	19	20	32	2	3	
45	13	19	20	32	2	3	
46	13	19	20	32	2	3	
47	13	19	20	32	2	3	
48	13	19	20	32	2	3	
49	13	19	20	32	2	3	
50	35	44	2	4	1	2	
51	35	44	2	4	1	2	
52	35	44	2	4	1	2	
53	35	44	2	4	1	2	
54	35	44	2	4	1	2	
55	35	44	2	4	1	2	
56	35	44	2	4	1	2	

Figure 1. The fictitious Square Mountain survey area has 56 sample units (SUs) of 12 mi² each and has 763 moose. Ten sets of 32 SUs each were randomly selected and used to calculate 10 estimates. The estimator of population size = (no. of moose observed in surveyed SUs/ area of surveyed SUs) \times total area.

from which 10 simple random samples of 32 SUs each were selected and surveyed. Two important points are demonstrated from results of the 10 surveys. First, population estimates are generally different (10 estimates ranged from 624 to 879 moose) and do not equal the actual number because of sampling error. Second, because sampling error is a random variable, it is impossible to tell how much an individual estimate differs from the actual value, i.e., how large the sampling error is for a particular sample, because the actual value is unknown.

Let us carry the idea of a sampling error of unknown size a little further. If a large number of random samples were taken from the Square Mountain population, the population estimates would form a distribution around the actual population size (μ) (Fig. 2). However, during an actual survey, you do not have the option of calculating a large number of estimates. Generally only one sample of n SUs is selected and searched for moose. Therefore, only one of the many

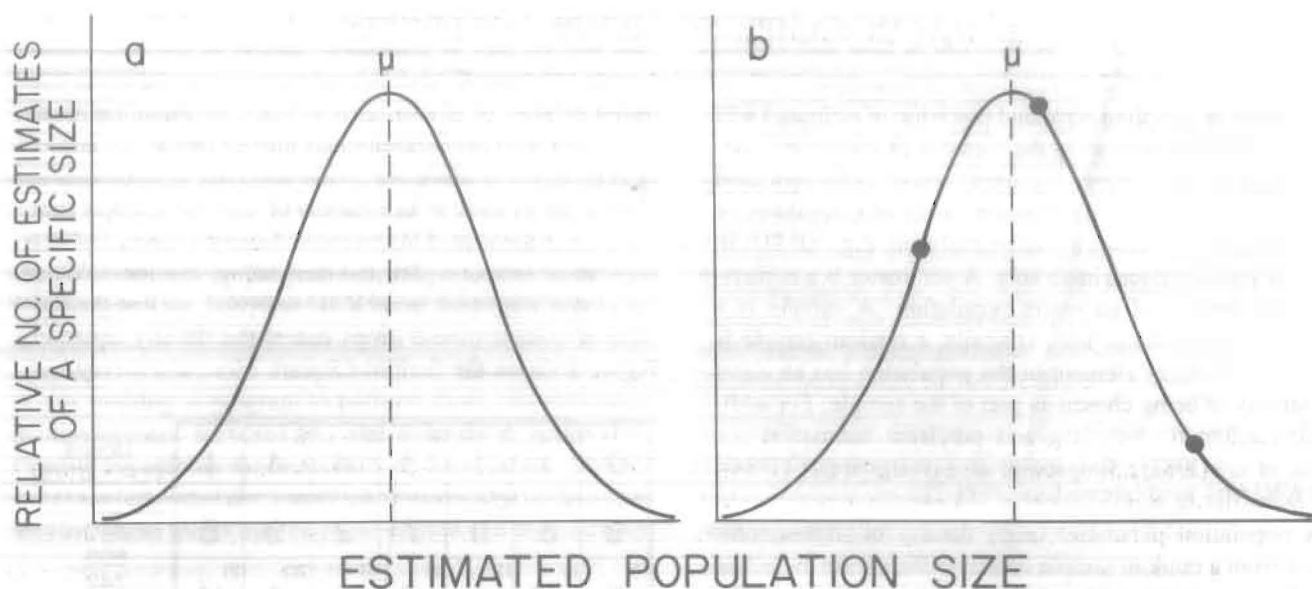


Figure 2. Frequency distribution of a large number of moose population estimates from the fictitious Square Mountain survey area. The actual population size equals m .

possible estimates of μ is obtained, and you cannot determine its location in the distribution of possible population estimates. The estimate may be very close to or far from μ .

Sampling error also occurs when estimating sightability. This sampling error has an effect on population estimates similar to that described above for density estimates. Therefore, the final error component for the population estimate is a combination of the two sampling errors. Without a measure of the potential size of these errors, we have no way of knowing how much faith to put into the population estimate.

Fortunately, there is information within a sample that allows the potential size of the sampling error to be estimated. This information is the variation among SU measurements—the greater the variation, the greater the potential sample error. A calculated measure of variation is called the variance. A formula for the sample variance of a simple random sample of x 's is

$$\text{sample variance of } x = \frac{\sum_j (x_j - \bar{x})^2}{n - 1}$$

where x_j is the measurement in the j th SU; \bar{x} is the mean of measurements in the sample of SUs, x_1, \dots, x_n ; n is the sample size ($n - 1$ is the degrees of freedom); and \sum_j indicates the summation of the values for each x_j . Conceptually, sample variance is the average squared difference between individual SU measurements and the mean measurement of all SUs. The sample variance is a measure of the variation in the population being sampled and is used to calculate the sampling variance of the sample mean \bar{x} . The sampling

variance is an indication of the potential size of the sampling error and is calculated as

$$\text{sampling variance of } \bar{x} = \frac{\text{sample variance of } x}{n}$$

Variance is used in part to measure the precision (repeatability) of estimates for density, sightability, and population size. Estimates of these parameters are of limited value unless precision of the estimates can be clearly specified. Although it is impossible to know the actual value of a parameter (e.g., number of moose), it is possible to describe a range of values, or interval, that is likely to include the actual value. This interval is the confidence interval (CI), and the specification of the CI is as important as the estimate itself (Simpson et al. 1960). For example, to have a population estimate of 1,000 moose for a study area is of little interest unless one has some idea how close it may be to the actual number.

A CI gives you a known probability ($1 - \alpha$) that the actual value of a parameter will be included within the CI. Another way of describing this concept is that, with repeated estimates, the CIs should include the actual population size a known percentage of the time. The probability of error (α) is the proportion of CIs, from all possible samples and their estimates, that would not include the actual value. The probability of successfully including the actual value in a CI is specified when calculating the CI, e.g., 0.9, which is equal to $1 - \alpha$ where the probability of an error (α) equals 0.1. The CI for an estimate has a specified probability of including the actual value, but you do not know for sure

Table 1. Population estimates and 90% confidence limits (CL) for 10 replicate surveys of 32 sample units from the fictitious Square Mountain survey area. The actual population is 763 moose.

	Survey number									
	1	2	3	4	5	6	7	8	9	10
Population estimate	840	805	742	788	801	624 ^a	714	677	733	879
Upper CL	1,024	973	905	974	968	761	870	824	895	1,048
Lower CL	656	637	575	601	635	487	558	530	572	709

^a Confidence interval for this estimate does not contain the actual population size.

that μ is within the CI or where μ is relative to each estimate of μ . To illustrate this concept, we calculated CIs for the 10 population estimates listed in Figure 1 for the fictitious Square Mountain survey area (Table 1). Each CI in Table 1 has a 0.90 probability of including μ , and as expected, 9 out of 10 CIs included μ . However, under actual survey conditions with only one estimate of μ , you will not know if your CI is one of those that includes μ ; the probability simply tells you the odds of that CI including μ . Now compare the 10 estimates of μ with the real μ . Some estimates are close to μ whereas others are well above or below μ ; additionally, no two estimates are the same. Because you will make only one population estimate for an area, the estimate will also be some unknown amount above or below μ . Therefore, you must depend on the CI to show the range in which the actual number may lie, and within that range, be prepared to accept the fact that μ may be near one of the CI limits or, infrequently, beyond a limit.

A general formula for a CI around an estimate (\bar{x}) of μ is

$$CI = \bar{x} \pm t_{\alpha, \nu} \sqrt{\text{sampling variance of } \bar{x}}$$

where \bar{x} is the estimate based on the mean value in SUs, and $t_{\alpha, \nu}$ is the critical t -value for the degrees of freedom (ν)

and the probability (α) from our level of confidence ($1 - \alpha$). The formula clarifies how the variance of the estimate is used to calculate the CI.

The two major factors determining CI width are the sampling variance of the estimate and the specified degree of confidence you desire, $1 - \alpha$. As variance increases, the CI width for a specified α increases and precision decreases. The CI width is also altered by the degree of confidence you specify for the estimate. Unfortunately, as you decrease the degree of confidence ($1 - \alpha$) to narrow the CI, the probability that the actual value is within that range also decreases. You must decide if it is better to be nearly sure that the number of moose lies within a wide range, or to be less sure that it lies in a narrower range. It is solely up to you to choose the level of confidence for each case.

We recommend striving for precision equal to or greater than a 90% CI with a width less than $\pm 25\%$ of the population estimate. Ideally, one wants a CI with a high probability of containing the actual number of animals but that is also narrow in width, e.g., 95% CI with a width of $\pm 5\%$ of the estimated number of moose. However, wildlife biologists cannot expect to obtain a 95% CI that narrow because the large sampling effort required makes it prohibitively expensive. Therefore, a reasonable compromise must be sought for moose population estimates.

3. ESTIMATING POPULATION SIZE

3.1 INTRODUCTION

Procedures for a survey to estimate population size may seem complex at first; however, they are less formidable when viewed as six steps.

1. Define the population of interest and select a survey area.
2. Delineate all possible SUs on a topographic map of the survey area.
3. Stratify the survey area by conducting a preliminary aerial survey to determine relative moose densities.
4. Select a random sample of SUs from each stratum.
5. Fly surveys of selected SUs and recount some areas using a more intensive search pattern to estimate the percentage of moose that were missed.
6. Calculate an estimate of population size and CI around the estimate.

3.2 SELECTING THE SURVEY AREA

3.2.1 Survey Area Boundaries

The choice of survey area boundaries is determined by your needs. Managers often want to estimate the number of moose in a natural population. Thus, physiographic features such as major river drainages and ridges are selected as boundaries. In other instances, the population estimate is for a site-specific management problem; here more arbitrary boundaries of game management areas, study areas, refuges, parks, or proposed industrial sites become appropriate.

3.2.2 Size of Survey Area

The size of the survey area will influence the success or failure of a population estimation survey. Survey areas may range from 300 to 4,000 mi²; smaller survey areas can usually be searched in their entirety, and larger survey areas will usually be impractical due to time constraints. Size of survey areas is dictated by the following variables:

1. *Precision desired.*—A survey area must decrease in size as precision of the estimate is increased, assuming a fixed cost. Precision is directly related to cost (see Section 3.11).
2. *Weather.*—Size of a manageable survey area is influenced by dominant weather patterns. Approximately 3 and 8 days of good flying weather are necessary to complete surveys of 300 and 4,000 mi², respectively. Large survey areas are practical only if long periods of good flying weather and snow conditions are predictable. When acceptable weather conditions last only a few consecutive days, small areas should be selected or

large areas partitioned into several smaller areas. The important point is that a survey should be completed as rapidly as possible. If bad weather halts the operation long enough for moose distribution to shift substantially, you may be forced to start over.

3. *Manpower.*—Survey area size should be adjusted to the available manpower. At least three experienced pilot-observer teams are required to complete a survey rapidly. Large survey areas (3,000 to 4,000 mi²) should not be attempted with less than four teams; five teams are preferred.

4. *Logistics.*—Considerations of cost and time available are important when selecting the size of the survey area. Surveys in remote areas increase fuel and lodging costs and may take longer to complete than surveys in less remote areas.

5. *Moose movements.*—If moose are expected to move extensively during the survey, select a small survey area or reschedule the survey.

3.3 SAMPLE UNITS

3.3.1 Defining Sample Units

A SU is the smallest delineated portion of the survey area that has a probability of being selected and searched in its entirety for moose. All moose habitat in the survey area is divided into SUs. Only that habitat which is clearly not suitable for moose is excluded. Generally, excluded habitat includes only glaciers, large lakes, and high portions of mountains; define these areas on a map prior to delineating SUs.

3.3.2 Drawing Sample Units

SUs are the foundation for the entire survey and must be drawn with a great deal of forethought. SUs should be drawn in pencil on maps of approximately 1:63,360 scale. A master survey area map should be hung on a wall in survey headquarters for logistical purposes. Consider the following factors when drawing each SU: (1) proper size and shape, (2) identifiable boundaries, and (3) habitat and moose distribution.

3.3.2.1 Sample unit size and shape

SU size should range from 11 to 13 mi², although some may be out of this range because of lack of sufficient natural boundaries. Avoid making SUs smaller than 9 mi² or larger than 15 mi². Consistency in SU size improves precision of population estimates using our estimators because variation in SU size increases variance of the population estimate. The shape of SUs should be conducive to aerial searching. Avoid drawing SUs with narrow extensions protruding from

the main body of the SU. After drawing each SU, visually estimate its size to confirm that it is 11 to 13 mi². A clear plastic template equaling 12 mi² (3 × 4 mi) on the map can be used to quickly check SU area.

Our SUs are large compared to SUs in most other sampling methods used to estimate numbers of moose. The reasons are: (1) easily identified natural physiographic features used to define SUs on maps do not occur with sufficient regularity to consistently describe small SUs; (2) fewer SUs are required if they are large than if they are small; therefore, the cost of flying between SUs and locating boundaries is reduced; and (3) for a fixed sum of money, sampling variance and CI width can be reduced by using large SUs, particularly in low-density moose populations.

3.3.2.2 Sample unit boundaries

Boundaries must be identifiable from the air; therefore, persons drawing SUs should be familiar with the survey area, survey procedures, and using topographic maps in flight. You will find SUs easiest to draw in hills and mountains and most difficult on flat, uniform terrain. Boundaries of SUs are generally trails, roads, lakes, gullies, creeks, rivers, ridges, and contour lines defining the upper limit of moose habitat; however, straight lines between two identifiable points are used when good topographic features are not available. Forks or bends in creeks, lakes, and peaks on ridges are convenient starting or ending points for straight boundary lines (Fig. 3). Straight line boundaries are difficult to define precisely from the air. For this reason, these vague boundaries should be placed in areas of very low moose density to minimize numbers of moose that may occur on or near the boundary. For example, dense spruce forest may have a very low moose density, hence a poorly defined boundary through it presents little problem because few moose will be encountered. A compass or visual heading is flown along the boundary while observations are made from only one side of the aircraft. This flight path establishes the boundary; subsequent flight lines are made toward the interior of the SU.

3.3.2.3 Habitat and moose distribution in sample units

Attempt to draw SUs that have uniform moose distribution and have boundaries that avoid habitat where moose are likely to concentrate. A uniform moose distribution within SUs speeds and improves the accuracy of stratification, which results in a more precise estimate of population size. Figure 4 shows a SU along a river drainage where moose concentrate near or above timberline. SU1 (Fig. 4) was drawn to include the alpine from the upper limit of moose habitat (4,000-ft contour) on the north side of the drainage, through the lowlands, and up to the limits of moose habitat on the south side of the drainage. SU1 contains a mixture of habitats with moose densities ranging from high on the upper side hills to low in the lowlands. This area can be redrawn into two more appropriate SUs, each having more

STRAIGHT LINE BETWEEN

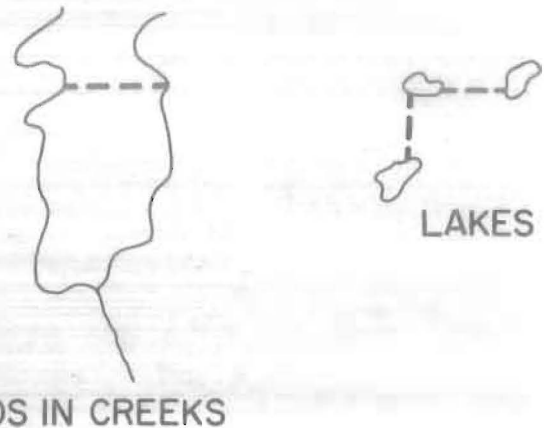


Figure 3. Straight line boundaries between topographic references are used to define sample unit boundaries when more prominent features are not available.

uniform habitat and moose density, e.g., SU2 and SU3 (Fig. 5). SU2 is drawn to enclose mainly subalpine and alpine habitat where moose densities are anticipated to be high, whereas SU3 (Fig. 5) contains mostly lowland habitat. SU2 and SU3 have a more uniform moose distribution than SU1. By drawing a new boundary on the 2,500 ft contour (Fig. 5), we have created a boundary that is impossible to locate exactly. However, in this drainage, moose are infrequently found in forested habitat near 2,500 ft elevation. Therefore, the imprecise boundary will cause few problems.

3.3.2.4 Numbering sample units

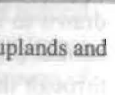
Give each SU a unique number for easy identification. Numbers are color coded for rapid relocation on the master survey area map. Blocks of approximately 50 contiguous SUs should each have a unique color.

3.3.2.5 Example: sample unit boundaries

Figure 6 illustrates SUs in mountainous and flat terrain. Each SU is between 11 and 13 mi² and can be easily distinguished when viewed from an airplane. Follow the boundaries of each SU noting the landmarks. Moose in the mountainous SUs of this area are commonly found in riparian willow along small creeks and gullies; therefore, most boundaries follow ridges. Creeks and gullies are avoided except in a few cases. In the lowland SUs, moose are distributed along the major river bottom; therefore, rivers are rarely used as a boundary. Straight line boundaries pass through black spruce forest where few moose are encountered.

3.4 STRATIFYING

To improve precision of the population estimate, one can either increase the number of SUs surveyed or use a sam-



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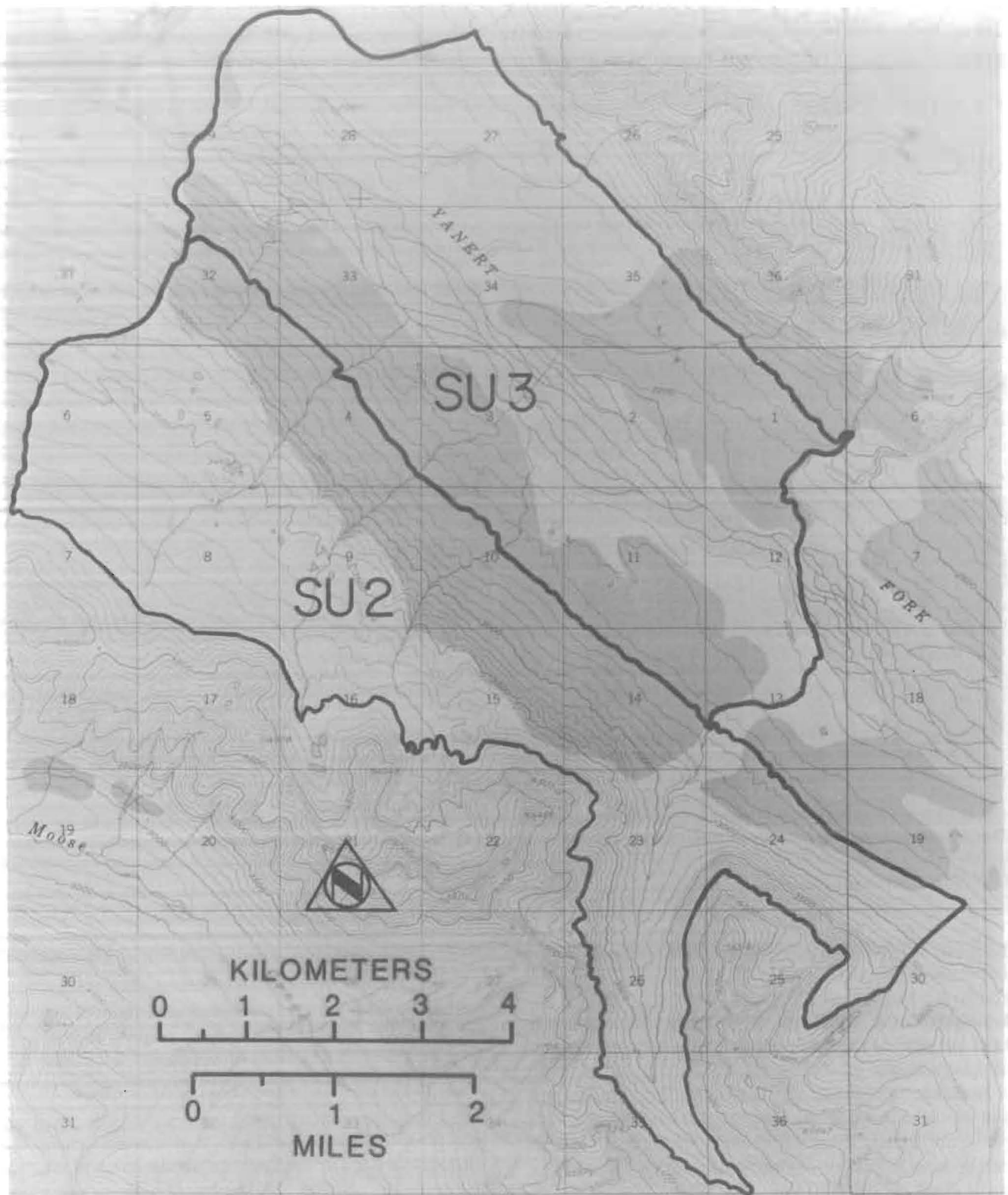


Figure 5. Sample unit 1 (SU1) in Figure 4 is redrawn into two new SUs, each having a more uniform moose distribution. Sample unit 2 (SU2) is upland habitat, and sample unit 3 (SU3) is lowland habitat. During early winter, moose concentrate in upland habitat.

way, the variance within strata is kept small, and this variance is used to estimate the precision of the population estimate.

In addition to increasing precision, stratification allows one optimally to allocate sampling effort among strata, thereby getting the most precision for your dollars (see Sec-

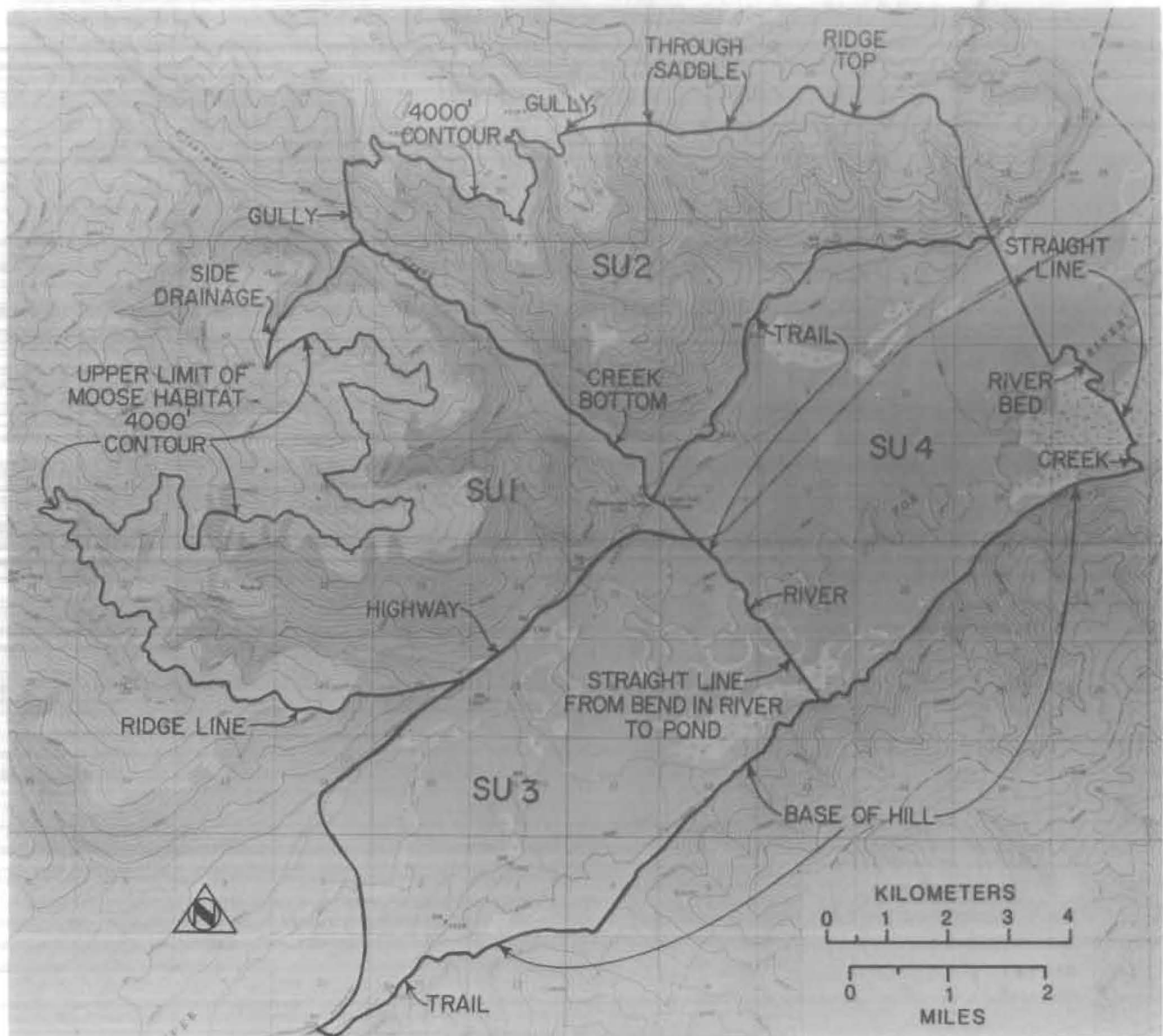


Figure 6. Example of sample units (SUs) in mountainous and lowland terrain. SU boundaries are creeks, gullies, ridges, rivers, straight lines between two points, and other features.

tion 3.8). In our experience, high-density strata generally have the greatest variance and, therefore, require the most sampling effort.

Stratification of the survey area is one of the most important aspects of estimating moose population size. The field procedure for stratifying involves classifying each SU into one of several relative moose density categories during a preliminary survey. Without a reliable stratification, it may be financially impossible to obtain a precise estimate. If stratification is done improperly, SUs will not be segregated into groups of relatively uniform density, causing increased variance, sample sizes, and costs. However, even a poor stratification will likely improve precision compared to unstratified random sampling.

3.4.1 Stratification Process

3.4.1.1 Number of strata in a survey area

The number of strata within a survey area is based on your ability to identify areas having relatively homogeneous densities of moose. Generally, only three strata can be identified accurately. Suggested designations are high, medium, and low density. Occasionally, a fourth stratum will be found that consists of very high or very low density. This additional stratum usually has only a few SUs and therefore is surveyed in its entirety.

Moose densities within a stratum are relative values for that particular survey. For example, a high-density stratum

may contain 1.8 moose/mi² in one survey area, and 3.2 moose/mi² in another.

3.4.1.2 Personnel and aircraft requirements

Stratification is most efficient with one crew consisting of three observers and a pilot. The observer sitting adjacent to the pilot navigates and records observations. The other two observers sit in backseats and search for moose and moose tracks and evaluate habitat. Only one crew is used to ensure consistent stratum classification among SUs. Stratifying SUs is subjective; therefore, two independent crews have difficulty maintaining continuity of classification. In our experience, savings in time with two crews were offset by larger variances resulting from inconsistent classification of SUs. Stratify using aircraft that fly 120 to 160 mph and carry three observers, e.g., a Helio Courier or Cessna 185, 206, or 207. Slow-flying aircraft such as Super Cubs, should be used only when faster aircraft are not available. However, if a slow-flying 2-place airplane is used, flying at cruising speed is best. The pilot and observer must perform all the functions of a 4-person crew.

It can be advantageous to use a second plane for stratifying when only a few SUs remain to be stratified. Specifically, a Super Cub may be used to finish the stratification, thereby freeing two observers to begin searching SUs. The observer in the Cub should be a member of the original stratification crew.

3.4.1.3 In-flight procedures

Begin stratifying in those areas that you think have the highest and lowest densities. This allows the crew to observe and discuss the likely extremes in density.

Although the crew members must strive for accuracy, they must do so while stratifying at an average of 140 mi²/hour (12 to 13 SUs/hour). The following factors necessitate this rate of speed.

1. Stratification is expensive. A Cessna 185 rented for approximately \$185/hour in 1985, which totaled approximately \$1,000 for a typical day's flying.
2. Surveying SUs cannot begin in full force until stratifying is complete. Delays increase the chance that bad weather will interrupt the survey.
3. Moose distribution is continually changing; therefore, the stratification becomes less accurate as time elapses between stratifying and surveying. Precision of the population estimate declines as the quality of the stratification deteriorates.

Flight time must be used efficiently for stratification to progress rapidly. Be prepared, use a fast airplane, and work long days. The navigator must locate SU boundaries on maps; therefore, have an accomplished map reader navigate so flight time is not wasted finding your location. A full day of map reading is exhausting when flying at 140 mph and

200 to 400 feet above the ground, so it helps to have two "mappers" in the crew. Increase the height of the aircraft above ground as the forest canopy becomes taller. The increased height improves the sightability of moose and moose tracks in tall timber.

Maximizing the efficiency of your flight path through each SU speeds stratification. An efficient flight path is illustrated in Figure 7a; this involves one pass along the side

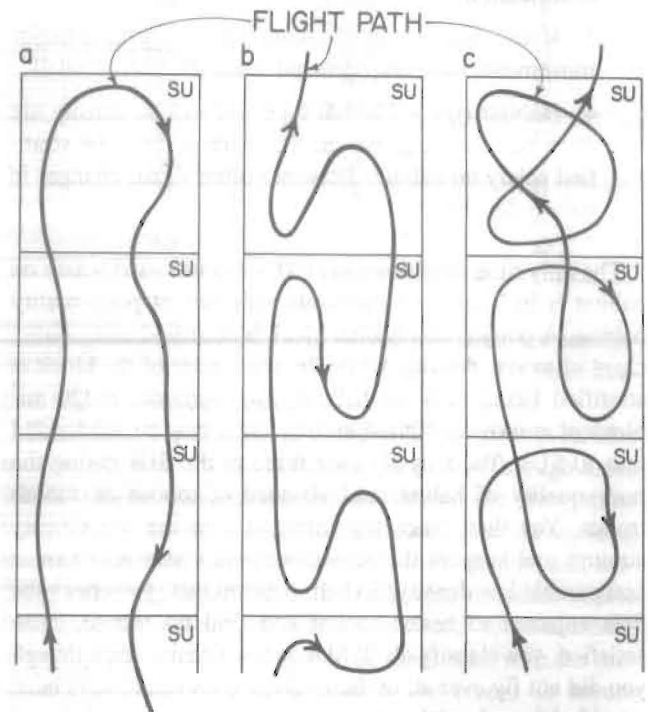


Figure 7. Examples of stratification flight path through sample units (SUs). (a) Recommended flight path that maximizes efficiency of flight time. (b) Flight path is too long for routine use but may be useful in SUs that are difficult to stratify. (c) Flight path is extremely long and rarely should be used.

of several SUs and then doubling back through the SUs. This flight path requires careful navigation and note-taking for each SU. The flight path in Figure 7b is $1.3 \times$ longer than the flight path in Figure 7a; it may be useful when a little extra search effort is required in a SU. Because each SU must be stratified, there is a tendency to look at one SU at a time (Fig. 7c). This method invariably results in an excessive amount of search effort per SU and is approximately $1.6 \times$ the length of the path in Figure 7a.

Spend the most time stratifying those SUs that are difficult to classify and the least time in easy SUs. Remember, the stratification flight is a superficial survey.

Stratification is based on a subjective evaluation of moose density, so use all clues that might indicate relative density. The following clues are helpful:

1. *Prior knowledge of moose distribution.*—This knowledge is based on previous surveys and habitat

use. Previous surveys are most useful if they have flight routes and locations of moose recorded. If the area was stratified previously, a copy of that stratification map will be useful.

2. *Relative number and distribution of moose seen during stratification.*—This is the most useful clue for stratification. Remember, however, that on the average 50 to 75% of the moose will be overlooked during stratification.

3. *Moose tracks.*—Track abundance is useful if major movements have not occurred since the last snowfall.

4. *Habitat type.*—Habitat type and moose density are often correlated. However, SUs should rarely be stratified solely on habitat. Ecotones often signal changes in moose density.

The only time stratification of SUs can be based solely on habitat is in large, homogeneous expanses of poor-quality habitat. A portion of a habitat block is stratified using direct clues of moose density, while the remainder of the block is stratified based only on habitat. For example, a 120-mi² block of muskeg and black spruce forest may be subdivided into 10 SUs. You may fly over three of the SUs noting the poor quality of habitat and absence of moose or moose tracks. You then place the three SUs in the low-density stratum and suspect the remaining seven SUs also have a comparable low density. To help confirm this, you check the SUs adjacent to better habitat and find no moose. Now satisfied, you classify all 10 SUs as low density, even though you did not fly over all of them. Some SUs would have been stratified based solely on habitat rather than on observed moose density. SUs stratified solely on habitat should be noted because this criterion becomes important if you re-stratify during the survey.

Recording the flight path, observations of moose and tracks, dominant habitat, and the stratum designation for each SU is mandatory during the stratification flight. This requires good communication among observers via a 4-way intercom. Portable units can be used in any plane. The backseat observers and pilot simply call out the number of moose or moose tracks seen to the navigator-recorder who marks the flight route and observations on the map. Each SU is placed into a stratum immediately after the SU is searched. If changes in SU boundaries or stratum classification are made later (but before sampling), the notes on moose, tracks, habitat, and flight lines will be invaluable.

3.4.1.4 Example: stratifying an area

Section 3 of this manual presents summary data on 10 population estimates in the fictitious Square Mountain survey area (Fig. 1). The estimates were based on a random selection of 32 SUs from an unstratified population of 763 moose. If the Square Mountain survey area were stratified

based on moose density, a more precise population estimate should be produced with reduced sampling effort. Let us return to Square Mountain, stratify the survey area, and calculate 10 new population estimates.

Suppose you are in the stratification crew, and you just flew through SU27 collecting the following information:

1. 10 moose were seen.
2. Moderate number of tracks were present.
3. Habitat was generally good.
4. SU27 was surrounded by SUs already classified as medium density.
5. You expect high-density SUs to have at least 20 moose.
6. You expect medium-density SUs to have less than 20 moose.

While flying into the next SU, assimilate the facts and consider the following questions pertaining to SU27:

1. You saw 10 moose. Did you see sufficient tracks to indicate enough additional moose to make it a high-density SU? If there were not enough tracks to indicate equal to or greater than 10 additional moose, perhaps you saw a high percentage of the moose in this SU.
2. Should the SU be classified medium density? It is surrounded by medium-density SUs.
3. Is habitat quality the type associated with high densities?

You decide to classify SU27 as a high-density SU, and you stratify the remaining SUs using the same approach. There is some overlap in the range of densities within each stratum because stratification is not perfect.

Now that the stratification is completed, let us calculate 10 population estimates from stratified, random samples of 20 SUs each. Each sample was optimally allocated among three strata to minimize variance (see Section 3.8 for optimum allocation). The results of these estimates ranged from 698 to 849 moose, and precision of the estimates (90% CI) ranged from ± 7 to 12% (Table 2). In comparison, population estimates from the simple random samples of Square Mountain SUs ranged from 624 to 879 and the 90% CI ranged from ± 19 to 24% (Fig. 1, Table 2). Therefore, even with reduced sampling effort (20 versus 32 SUs), the estimates using stratification were more precise than those without stratification.

The stratified sampling technique produced estimates that had CIs averaging $\pm 10\%$ of the population estimate. However, if this level of precision were not needed, you could have sampled less than 20 SUs and still had better precision than that of the unstratified survey, resulting in saving time and money.

Table 2. Ten population estimates based on simple random samples of 32 sample units and stratified samples of 20 sample units from the fictitious Square Mountain survey area. The actual population is 763 moose.

Survey no.	Simple random sample			Stratified sample		
	Estimate	Variance	90% CI (% of estimate)	Estimate	Variance	90% CI (% of estimate)
1	840	11,727	22	763	1,700	9
2	805	9,846	21	849	1,596	8
3	742	9,245	22	733	2,533	12
4	788	12,090	24	755	2,619	12
5	801	9,694	21	775	1,947	10
6	624	6,736	22	759	2,418	12
7	714	8,457	22	782	2,315	12
8	677	7,512	22	819	1,075	7
9	733	9,046	22	717	2,003	11
10	879	10,008	19	698	1,165	10
Mean	760		22	765		10

3.4.1.5 Redrawing sample unit boundaries before surveying

Some SU boundaries will need to be redrawn during and after the stratification flight but before being surveyed. The two situations that require redrawing of SU boundaries are:

1. *Highly variable moose densities occurring within a SU.*—Despite the initial attempt to make density uniform, some SUs may have both high- and low-density portions. If this makes it difficult to assign a SU to a stratum, redraw the boundaries of it and adjacent SUs as described in Section 3.3.2.

2. *Concentrations of moose on or near strata boundaries.*—Localized movement of moose may occur between adjacent SUs after stratification. The problem is most critical when moose move into lower density strata. Local movements generally increase the variance in the lower stratum more than the variance in the higher stratum.

A solution to the problem of moose moving between strata is to redraw the SU to include some lower density area within the perimeter of a high-density SU. This low-density strip helps ensure that moose within an adjacent medium- or high-density SU will be in the SU when it is later surveyed. For example, imagine a burned area subdivided into SUs. Each SU is stratified as high density and surrounded by black spruce forest that was classified as low density. A large number of moose may wander between the burn and the margins of the spruce. Therefore, the best SU boundary is within the spruce forest rather than at the edge of the burn. A subjective judgment must be made to determine where the influence of the edge grades into actual low moose density. We recommend extending the higher density SU 0.25 mi or more into the lower density area (Fig. 8).

Even though some SUs will be redrawn after the stratification, drawing SUs prior to stratification helps stratification flights proceed rapidly.

Sometimes the absence of topographic features precludes moving SU and stratum boundaries that pass through areas where moose concentrate. In this case, the new strata boundary is moved a specified distance from the existing boundary. An example is where SUs from the low and medium strata are separated by a creek with no other usable boundary for miles. Because moose tend to concentrate along riparian willow, many moose associated with the medium SU could be on either side of the creek. To ensure these moose are counted in the medium SU, the entire riparian willow strip should be included in the medium SU. Remember, the decision to include the entire riparian strip must be made before searching the SU, thereby holding bias to a minimum.

To indicate this special boundary situation, color the outside of the new medium-density SU boundary with a transparent colored marker. The colored mark indicates a predesignated boundary situation, e.g., the entire riparian strip, or a 100-yard strip beyond the creek. Adjusted SU boundaries are transferred to a master survey area map.

3.4.1.6 Changes in stratification during the survey

Restratifying during the survey may occasionally be legitimate. Areas incorrectly stratified might be identified while flying to and from SUs or while surveying adjacent SUs.

When the initial stratification was based on observed moose density (i.e., abundance of tracks or numbers of moose seen), incorrect stratification may be the result of moose movements during the survey, errors in track identification during stratification, or poor choices of SU boundaries. If errors are gross, it may be worthwhile to do another stratification flight for the SUs in question.

Table 3. Random numbers from 1 to 440. Numbers were generated on the Hewlett-Packard 97 calculator.

Row	Column																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	384	225	54	142	257	104	269	92	414	170	60	155	209	363	272	295	414	135
2	337	29	186	228	167	57	138	275	331	61	138	38	284	47	79	234	145	135
3	45	136	437	427	26	146	124	393	7	92	231	257	403	414	384	373	48	305
4	143	297	420	362	252	265	284	427	150	150	334	301	67	361	153	259	276	60
5	13	269	244	68	131	299	414	190	220	79	182	64	143	122	243	81	248	327
6	432	158	160	71	207	384	353	165	255	198	59	394	348	267	160	310	279	341
7	160	271	419	132	429	99	437	156	121	324	210	424	252	249	289	357	150	34
8	401	407	157	288	67	121	184	348	396	419	223	39	290	47	125	152	132	291
9	133	326	54	326	15	276	80	429	195	58	401	169	51	307	339	431	148	224
10	64	134	226	178	14	301	149	74	389	393	273	41	178	373	18	15	130	320
11	272	271	253	16	238	404	323	353	95	209	400	149	211	419	202	5	134	286
12	154	312	139	314	68	351	206	31	224	78	400	398	295	344	89	331	422	420
13	439	152	223	408	347	83	56	145	136	425	408	176	143	302	102	249	41	57
14	370	358	264	91	283	118	136	205	285	27	161	180	407	325	125	279	410	25
15	196	184	332	401	349	132	210	193	350	122	113	157	361	268	223	298	64	419
16	263	434	298	140	157	276	217	361	401	89	118	145	422	130	221	46	354	335
17	281	249	29	36	189	340	308	361	428	209	245	152	34	3	433	298	150	94
18	353	335	177	64	192	250	256	357	72	211	369	89	41	2	290	36	282	440
19	159	350	45	440	354	303	262	122	113	396	194	20	286	367	376	215	252	35
20	1	391	382	124	153	39	181	262	106	8	214	332	426	89	435	73	260	426
21	72	260	247	137	158	149	330	352	374	328	131	91	364	347	196	217	322	72
22	29	75	49	79	224	208	313	109	14	260	350	285	135	58	416	405	216	322
23	16	20	404	127	121	114	302	362	101	1	127	62	250	129	80	328	266	403
24	221	248	121	60	344	37	73	366	350	65	90	224	5	159	320	225	99	397
25	323	21	167	37	253	225	48	328	54	213	18	329	171	86	396	336	440	264
26	32	63	374	204	25	185	172	312	248	220	409	135	238	270	383	264	246	107
27	311	115	185	21	188	297	257	397	111	193	28	126	226	46	120	244	231	277
28	109	247	347	97	101	31	40	331	291	76	128	361	28	145	396	276	331	52
29	405	87	355	15	206	424	120	265	351	125	261	276	73	386	233	115	136	225
30	141	7	289	65	213	208	34	93	184	138	261	5	101	150	175	152	253	228
31	247	380	296	170	249	141	403	28	46	135	74	176	349	272	312	198	338	146
32	98	361	343	64	203	375	258	104	379	187	75	139	91	145	392	21	397	350
33	368	259	126	303	68	71	190	201	103	310	8	308	316	387	292	36	169	258
34	329	44	266	274	11	392	58	31	163	250	340	178	401	245	11	370	130	317
35	46	209	33	374	4	283	438	97	378	66	205	181	364	210	264	11	291	325
36	252	350	62	153	222	210	230	406	16	110	273	311	96	368	129	430	119	310
37	334	211	252	398	59	114	297	210	213	412	10	158	150	233	176	331	102	189
38	415	110	217	350	276	87	195	218	331	8	291	415	388	413	330	322	84	119
39	172	126	153	29	245	426	256	187	150	334	164	175	3	34	429	318	156	63
40	127	371	208	215	328	243	111	68	198	405	205	304	95	202	105	191	179	313
41	48	25	276	290	107	235	365	220	201	303	192	66	335	337	50	247	51	14
42	51	77	119	200	353	151	63	433	228	103	142	256	286	430	85	236	368	396
43	59	414	375	333	181	432	108	354	104	239	109	64	22	87	326	280	124	303
44	84	362	271	102	341	55	276	20	319	440	433	407	324	194	438	426	276	61
45	154	383	271	12	130	151	435	36	203	62	347	93	426	40	347	286	147	406
46	63	292	126	98	71	390	413	321	385	263	436	367	431	47	169	163	229	266
47	226	234	235	64	424	367	10	221	100	427	176	255	229	403	137	67	343	354
48	365	270	82	412	176	101	44	161	246	281	146	420	45	166	398	169	125	92
49	340	235	144	125	70	370	209	250	299	2	215	298	423	240	24	243	23	78
50	1	364	262	52	70	207	122	193	200	83	436	216	52	293	35	262	186	161
51	75	145	245	331	394	290	96	78	128	382	41	323	341	128	210	34	281	355
52	423	172	282	426	16	409	202	205	346	33	363	161	101	27	255	397	424	190

Table 3. Continued.

Row	Column																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
53	345	417	322	56	45	380	120	130	400	8	213	259	207	14	41	297	321	322
54	153	294	351	335	332	142	113	225	79	44	349	145	316	283	63	151	265	34
55	82	97	381	236	216	352	283	148	144	257	184	262	355	315	284	78	334	237
56	249	163	56	342	371	158	88	286	44	370	28	366	96	272	142	97	184	341
57	307	177	324	44	230	117	218	80	197	79	304	201	106	10	128	1	159	397
58	287	226	389	59	241	232	74	120	220	330	92	344	124	302	181	54	329	382
59	362	348	206	154	15	270	123	103	143	338	399	16	159	17	259	147	16	426
60	145	315	198	403	319	266	291	135	148	345	84	66	82	428	185	121	40	332
61	27	282	329	12	54	207	243	373	4	293	374	388	139	287	136	163	258	77
62	112	76	50	154	350	175	9	164	409	125	373	124	42	330	93	429	328	264
63	167	121	371	19	314	399	258	46	320	212	307	211	399	319	426	321	361	72
64	262	36	439	245	145	155	82	297	123	127	241	52	438	392	201	256	370	60
65	191	101	151	260	401	59	49	425	220	319	437	342	38	271	13	27	271	102
66	253	338	30	261	378	80	106	358	294	381	155	161	91	80	27	45	59	235
67	381	191	39	211	314	128	138	24	406	290	167	297	104	186	211	172	131	300
68	350	365	401	144	419	118	135	158	86	152	113	126	213	139	58	336	132	371
69	18	108	417	384	134	298	7	142	316	218	277	50	317	98	48	158	75	359
70	268	130	10	1	394	317	320	47	325	364	350	366	16	279	349	197	282	350
71	399	428	50	274	107	88	104	339	139	18	135	250	306	60	68	318	262	365
72	196	404	427	199	26	192	216	360	223	315	247	200	438	2	194	48	440	286
73	348	56	397	136	409	335	419	68	431	377	67	158	241	242	243	318	164	119
74	217	351	267	50	52	163	46	438	346	283	268	363	212	359	82	326	71	387
75	108	24	206	244	349	15	225	145	315	387	114	262	135	408	197	44	243	51
76	158	140	188	157	160	36	230	396	361	108	248	180	84	422	381	314	428	380
77	218	127	11	20	132	109	429	435	26	14	336	120	303	22	153	202	25	297
78	225	93	309	39	138	264	45	360	92	403	148	381	55	295	185	188	70	111
79	162	19	127	102	375	366	411	364	332	98	101	210	284	364	341	138	406	427
80	78	225	218	250	171	103	439	82	177	374	28	421	421	81	58	61	86	255
81	137	379	367	236	110	117	434	426	220	206	409	136	395	80	17	220	337	11
82	235	91	74	439	296	190	136	408	375	288	263	423	142	243	2	245	387	313
83	269	313	297	220	340	298	378	146	244	142	433	267	433	268	330	222	98	304
84	97	265	11	281	424	137	218	81	93	33	193	60	431	227	28	331	41	130
85	173	337	376	266	132	68	22	397	196	338	259	207	380	186	100	30	361	148
86	300	373	57	166	152	182	144	377	403	217	60	135	255	418	53	343	4	343
87	369	335	220	179	3	423	198	247	132	6	102	89	55	2	344	87	359	129
88	310	189	411	261	70	102	246	287	207	224	189	337	420	381	146	121	141	166
89	340	326	244	8	366	90	223	208	135	335	211	424	409	305	232	292	189	387
90	78	9	11	432	213	363	305	60	285	294	284	167	299	189	320	425	123	302
91	263	326	100	140	328	323	311	145	5	362	232	242	132	139	428	135	3	280
92	203	215	99	157	104	330	418	322	46	315	427	59	136	265	394	240	89	54
93	205	331	312	138	99	111	284	94	82	356	44	16	359	342	5	350	387	209
94	344	207	243	382	146	106	36	119	284	337	221	66	352	404	148	371	343	107
95	118	4	424	437	56	255	419	88	314	427	129	337	111	83	296	113	47	305
96	350	362	231	345	178	250	99	260	222	19	20	427	262	172	286	317	328	79
97	58	56	282	69	161	401	105	379	365	141	180	440	361	358	153	382	195	284
98	293	175	365	101	67	12	90	395	307	160	355	313	340	49	227	178	370	318
99	330	210	303	341	29	241	83	100	21	207	199	413	368	149	340	289	196	89
100	85	172	175	26	342	162	271	440	409	195	344	147	16	369	278	281	235	204
101	138	339	216	271	12	412	144	155	223	285	356	30	355	43	411	161	420	81
102	427	329	394	47	319	306	102	126	121	303	294	134	146	181	333	421	222	245
103	13	217	381	284	139	94	20	139	124	272	410	291	175	25	24	273	412	64
104	361	183	79	148	104	30	21	178	85	432	115	265	344	337	151	20	318	86
105	317	136	189	187	381	84	397	346	377	86	295	270	124	212	63	259	136	428

Table 3. Continued.

Row	Column																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
106	426	156	311	309	151	280	169	46	180	110	332	91	73	199	128	249	319	177
107	318	187	437	306	160	151	200	177	254	279	325	251	232	357	200	207	74	150
108	246	260	87	151	103	189	391	378	236	174	189	190	432	177	34	184	198	357
109	226	94	133	59	435	343	48	208	305	257	81	353	287	137	177	155	18	298
110	327	243	403	294	164	418	343	14	30	401	354	153	292	95	382	246	129	100
111	285	238	63	404	23	367	229	127	188	67	223	295	415	403	58	164	320	92
112	253	425	260	76	130	147	215	31	335	257	364	150	314	295	235	361	332	221
113	57	151	370	99	130	311	83	16	200	263	154	268	313	319	162	299	322	176
114	295	384	315	24	226	127	122	199	437	105	203	415	61	180	163	38	282	35
115	240	159	90	193	10	278	40	370	339	176	14	126	34	313	180	170	97	61
116	214	53	303	84	327	300	343	237	295	51	378	85	326	403	388	349	436	176
117	247	230	257	343	238	3	294	281	279	319	417	219	227	177	285	184	2	33
118	377	233	295	184	103	276	151	193	410	231	20	77	433	317	413	9	332	101
119	6	52	208	360	112	136	159	367	40	41	399	395	376	76	20	334	81	87
120	1	164	238	14	316	237	253	209	420	212	60	134	53	316	78	174	45	329
121	412	425	46	39	111	28	304	130	341	265	170	323	11	192	356	283	88	316
122	424	205	384	185	328	43	369	320	122	63	223	80	58	155	251	20	164	159
123	64	223	258	308	256	307	369	290	302	192	179	125	216	331	121	154	59	55
124	189	10	411	366	417	233	315	348	234	74	370	125	201	26	17	335	100	430
125	62	203	206	421	231	285	68	38	12	350	246	267	73	359	113	43	50	77
126	324	174	376	133	429	278	211	189	170	386	14	396	172	355	238	360	312	348
127	230	46	110	64	423	56	332	241	92	258	263	245	284	294	294	104	120	420
128	211	394	167	68	261	277	417	93	213	343	210	113	15	176	135	248	221	396
129	357	329	362	321	86	82	57	155	73	246	131	110	267	174	135	80	384	184
130	148	201	196	127	392	219	30	305	122	232	426	246	53	276	322	12	241	152
131	241	392	282	145	265	214	193	405	72	351	262	356	255	67	223	135	389	32
132	33	403	367	99	432	4	233	265	175	51	377	366	400	209	40	141	26	87
133	34	279	279	329	314	54	56	405	385	63	202	197	354	35	89	4	403	342
134	14	410	55	317	153	372	437	237	10	71	240	374	152	429	198	406	107	125
135	24	166	17	380	112	56	355	285	207	44	331	168	172	414	403	68	388	263
136	157	181	424	257	197	87	156	358	123	92	324	241	130	424	260	85	66	438
137	253	368	320	132	44	311	285	107	367	220	266	94	33	133	420	238	344	317
138	152	224	305	301	385	20	88	54	397	146	165	338	229	376	17	256	207	315
139	351	222	129	340	190	226	137	247	201	52	137	408	440	266	281	69	171	337
140	187	107	408	165	139	224	138	267	75	166	128	380	374	358	319	416	92	34
141	426	326	234	185	183	259	6	272	293	221	179	43	70	432	264	85	225	339
142	11	300	83	283	288	246	401	96	231	197	224	86	94	154	309	439	44	110
143	247	440	406	383	74	159	73	360	292	286	84	126	191	170	273	32	328	169
144	208	243	63	411	354	385	177	54	67	248	170	326	375	184	142	136	359	109
145	216	172	42	437	387	49	258	116	376	183	132	199	68	348	36	232	267	270
146	251	429	158	234	96	43	123	412	285	414	34	123	4	10	291	335	172	383
147	234	146	31	294	124	3	304	190	8	42	440	376	93	203	115	406	13	410
148	68	255	187	91	94	322	64	254	133	189	121	120	250	161	276	100	20	19
149	201	166	119	340	89	341	375	317	186	362	108	138	143	163	192	159	430	319
150	55	307	207	144	385	254	52	17	188	231	402	118	194	229	363	371	438	247
151	244	36	312	428	370	235	417	363	1	125	378	276	400	389	369	309	289	287
152	16	265	54	396	61	30	103	304	162	246	271	212	153	189	220	89	405	253
153	70	157	221	369	130	327	388	382	426	316	297	363	422	37	122	163	360	212
154	21	77	108	169	94	183	393	250	177	81	187	320	256	4	403	187	52	83
155	40	201	136	299	45	29	356	223	260	393	391	51	38	172	395	411	281	169
156	123	384	80	207	204	306	37	243	288	226	97	303	328	393	150	364	417	243
157	276	82	43	330	272	203	251	170	203	429	9	38	72	355	234	394	331	298
158	221	316	257	137	259	233	313	427	360	298	53	106	399	135	209	173	7	9

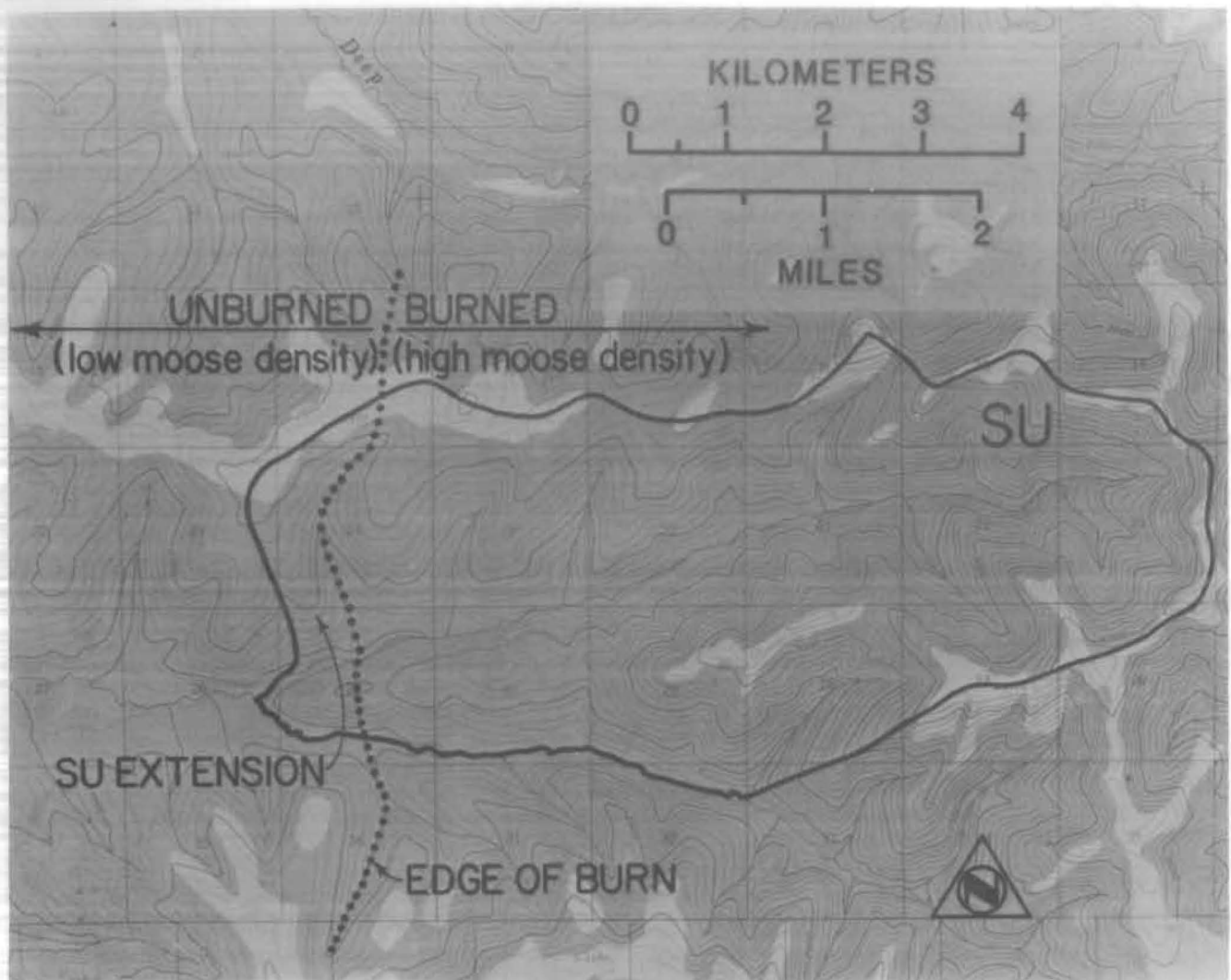


Figure 8. Example of strata and sample unit (SU) boundaries that accommodate moose movements between adjacent good and poor habitats. Instead of using the edge of the burn as the western boundary of this SU, the boundary was moved into the unburned area about 0.5 mi to the next identifiable topographic feature. Now moose that wander short distances into the poor habitat will be included in the high density SU.

When the initial stratification was based on factors other than observed moose density, e.g., habitat type, reassignment of strata for the SUs in question may be accomplished by assigning a different relative density to the habitat type in question or be based on the direct observations that initially caused you to question the stratification. A restratification flight may also be necessary.

If restratification is attempted, SUs that have been counted prior to the decision to restratify must stay in the initial stratum category. The SUs that have not been surveyed may be changed to a new stratum and sampled at the intensity of the new stratum.

Restratification of SUs should occur rarely and should be made judiciously. Restratification is reserved for a gross oversight or small areas where, for example, weather prevented a good initial stratification. Restratification privileges can be abused easily. Legitimate restratifying is done

to improve precision, but if abused, the result is a false level of precision.

Restratification invariably detracts from the true randomness of a random sampling scheme, which results in bias in the estimates and questions about the trueness of confidence intervals around the estimates. Because you cannot reclassify SUs that have been searched, the improvements in precision resulting from restratification may not be worth the effort required to restratify. Proceed with caution.

3.4.1.7 Timing of stratification

Stratification should be conducted just prior to the survey of SUs. Wait for proper conditions (adequate snow, little or no wind, and good light) and then rapidly stratify the area.

Timing of many moose population estimation surveys coincides with routine trend and composition surveys during

October–December. Unfortunately, the number of good flying days is limited, and biologists are tempted to conduct other surveys and stratification flights simultaneously. However, each type of survey is unique, and they should not be flown simultaneously. If both types of surveys are scheduled for nearly the same time, mapping groups of moose and flight routes during composition or trend surveys will speed stratification for that area.

3.5 SELECTING SAMPLE UNITS

3.5.1 Selection Process

A simple random sample of SUs is selected from each stratum using a table of random numbers (Table 3). Be sure to vary the starting point in the random number table with each survey so that the same sequence of numbers is not continually reused. Sampling is without replacement, i.e., a SU can be selected only once. Vertically list SUs in the order of selection on Form 1 (see Appendix 2 for blank form). Cross SUs off the list after their first appearance. Select 80% or more of the SUs in each stratum so that you will not have to return to the random number list. Indicate the stratum classification of each SU by placing a symbol (L, M, H) beside each SU number. On Form 2, list all SUs by stratum in the order of selection from Form 1 (see Appendix 2 for blank form).

3.5.2 Ensuring A Random Sample

The order in which selected SUs are searched is important to ensure randomness. The first five SUs selected in each stratum can be searched in the most efficient order. However, after the first five (or a greater predetermined minimum number), SUs should be searched in nearly the order of selection. By doing so, the survey can be terminated whenever adequate precision of the population estimate is attained and randomness will be assured.

Practically speaking, a SU that was selected may be skipped because of localized hazardous flying weather on the last day of the survey or because of poor snow cover. Omissions such as these should be rare. Simply replace a SU with the next one on the random number list from that stratum. Do not omit SUs for other reasons, e.g., long distances from airports. Subjective omission of SUs destroys the random selection process.

3.6 SURVEY METHODS AND ESTIMATING SIGHTABILITY

3.6.1 Timing of Surveys

Estimating moose population size in early winter (Oct–Dec) is preferable to late winter because sightability is greater in early winter. This, of course, is dependent on good snow cover in early winter, a condition that often does not occur in southern portions of North American moose

Table 4. Classification of snow conditions for sightability of moose during aerial surveys.

Age of snow classification	Coverage	Snow ranking
Fresh	Complete	Good
	Some low vegetation showing	Moderate
	Bare ground or herbaceous vegetation showing	Poor
Moderate	Complete	Good
	Some low vegetation showing	Moderate
	Bare ground or herbaceous vegetation showing	Poor
Old	Complete	Moderate
	Some low vegetation showing	Poor
	Bare ground or herbaceous vegetation showing	Poor

range. Sightability is higher during early winter because moose form larger groups (Peek et al. 1974, Mytton and Keith 1981, Novak 1981) and have stronger preferences for vegetation with low, open canopies (Lynch 1975, Peek et al. 1976, Mytton and Keith 1981). However, regardless of time of year, there are some habitat types that are too dense to see an adequate proportion of the moose during any type of survey, e.g., coastal spruce-hemlock forest in Canada and Alaska.

Survey methods in this manual were primarily designed and tested in early winter. If surveys cannot be conducted until late winter, alterations in the methods must be made. We have made recommendations for this period, but they are largely untested (Section 3.6.4). Recommendations are based on two late winter surveys in southwest Alaska, our late winter sightability experiments using radio-collared moose, experiments using penned moose on the Kenai Peninsula, Alaska (LeResche and Rausch 1974), and experiences in Canada (Novak and Gardner 1975, Thompson 1979).

3.6.2 Required Snow Conditions

Ensure satisfactory snow conditions exist throughout the survey area (good and moderate by our ranking in Table 4) before starting a survey, because snow conditions have a major influence on moose sightability. To help track changing snow conditions during the survey, snow conditions in each SU should be ranked good, moderate, or poor based on subjective evaluations of snow age and snow cover. Rankings are recorded on Form 3 at the time the SU is surveyed (see Appendix 2 for blank form). Subjective snow age and cover categories used in Table 4 are defined below.

Form 1. Simple random sample of sample unit numbers drawn from a random number table. List numbers in the order of selection within columns. Place L, M, or H after each number to indicate the assigned stratum.

Survey Area Fictitious Square Mountain

Game Management Unit(s) 1 Subunit(s) A

Date Nov 1983 Range of SU Numbers 1-56

Column

[illegible]

Form 2. Stratified random sample of sample units by stratum. Numbers are listed in order of selection within strata.

Survey Area Fictitious Square Mountain

Game Management Unit(s) 1 Subunit(s) A

Date Nov 1983 Range of SU numbers 1-56

Stratum

Low

Medium

High

Other

[illegible]

Form 3. Moose survey data gathered during standard or intensive searches of sample units.

SU no. 38 Date Nov 4 1983 Page 1 of 2

Survey area Fictitious Square Mountain

Pilot/obs. Gasaway/DuBois Est. area 12.0 mi²

Type of search: Standard (e.g., 4-6 min/mi²) ☒
Intensive (e.g., 12 min/mi²) ☐

Dominant habitat Low shrub-dominated burn

STANDARD SEARCH DATA SUMMARY

Strata H ☒, M ☐, L ☐, O ☐
Total moose seen 17
Min. searched 66
Measured area (mi²) 12.0
Search effort (min/mi²) 55
Obs. density (moose/mi²) 1.4

INTENSIVE SEARCH DATA SUMMARY

No. moose std. search 2
No. moose int. search 2
Int. search time (min) 30

WEATHER: Clouds overcast Precipitation none Temperature -12°F Wind 0-5 mph Turbulence none

LIGHT		SNOW AGE AND COVER				SEARCH TIME	
TYPE	INTENSITY	Fresh <input checked="" type="checkbox"/>	Moderate <input type="checkbox"/>	Old <input type="checkbox"/>	Complete <input checked="" type="checkbox"/>	Some low veg. showing <input type="checkbox"/>	Bare ground showing <input type="checkbox"/>
Bright <input type="checkbox"/>	High <input type="checkbox"/>						
Flat <input checked="" type="checkbox"/>	Med. <input checked="" type="checkbox"/>						
	Low <input type="checkbox"/>						

Stop time 11:37
Start time 10:31

REMARKS

In SCF plot (✓)	Group no.	Bulls/Activ.			Cows and calves/Activ.				Unk. sex-age	Total moose	Habitat moose are in
		Yrlg	Med	Lge	♀	♀/1 calf	♀/2 calf	Lone calf			
	1				3/L					3	H LS TS D SS S L
	2					1/L				2	H LS TS D SS S L
	3					1/L				2	H LS TS D SS S L
✓	4					1/L				2	H LS TS D SS S L
	5	1/L					1/s			4	H LS TS D SS S L
	6		1/L		1/s					2	H LS TS D SS S L
	7					1/2 L				2	H LS TS D SS S L
	8										H LS TS D SS S L
	9										H LS TS D SS S L
	10										H LS TS D SS S L
	11										H LS TS D SS S L
	12										H LS TS D SS S L
	13										H LS TS D SS S L
	14										H LS TS D SS S L
Sex-age totals		Y= 1	M= 1	L=	♀= 4	♀= 4 Ca= 4	♀= 1 Ca= 2	Ca=	U=	17	= Total Moose

Table 5. The influence of habitat selection and search intensity on the sightability of moose during aerial surveys with good, moderate, and poor snow conditions. Data for early and late winter are combined.

Habitat selected	Percent radio-collared moose seen during standard search (4-6 min/mi ²)		
	Good snow	Moderate snow	Poor snow
Non-spruce ^a	87	83	68
Spruce ^b	60	30	0

^a Includes herbaceous, low shrub, tall shrub, deciduous forest, and larch forest.

^b Includes spruce forest and sparse spruce forest.

Snow Age

1. *Fresh*.—Generally less than or equal to 1 week since snowfall of greater than 3 inches. Old tracks are covered.
2. *Moderate*.—Generally greater than 1 and less than or equal to 2 weeks since fresh snow conditions. Newly fallen snow of less than 3 inches often is inadequate to renew the snow surface so that it appears smooth and disturbance-free; therefore, shallow new snow may be classed as moderate-aged based on appearance.
3. *Old*.—Generally greater than 2 weeks since fresh snow conditions. However, newly fallen snow subjected to melting conditions can rapidly appear like old snow, i.e., depressions around trees and shrubs, irregular surface, and enlarged animal tracks. Therefore, new snow may be classed as old after only 2 to 3 days.

Snow Cover

1. *Complete*.—Low vegetation covered. Generally 6 to 12 inches of snow are required.
2. *Some low vegetation showing*.—Tops of some grasses, forbs, or very low shrubs protruding through snow. Snow cover has a brownish cast.
3. *Distracting amounts of bare ground or herbaceous vegetation showing*.—Distinct brown patches exist that reduce observer efficiency. Stumps and fallen trees in burns have the same effect if not snow covered.

Snow conditions may deteriorate during a survey, so be sure that SUs have satisfactory snow conditions when searched so that high sightability is maintained throughout the survey. Sightability decreases as snow conditions deteriorate (Table 5).

Occasionally, surveys are started when a few SUs contain poor snow. Waiting for good or moderate snow throughout

large areas is often impractical. For example, localized wind-scouring of snow may routinely cause poor sightability in some mountainous SUs. If a SU with poor snow conditions is selected for searching, increase the search effort, or if need be, omit it and move to the next randomly selected SU.

3.6.3 Early Winter Surveys (Oct-Dec)

3.6.3.1 Search effort

Search effort (min of search/mi²) largely determines sightability. High sightability in the open canopy forests of Alaska is assured by maintaining a high minimum search effort that compensates for variation in survey conditions among SUs and from day-to-day. The observer must ensure adequate search time is put into each SU. In interior Alaska, search effort of 4 to 5 min/mi² was required to see most moose during early winter (Fig. 9). The minimum accept-

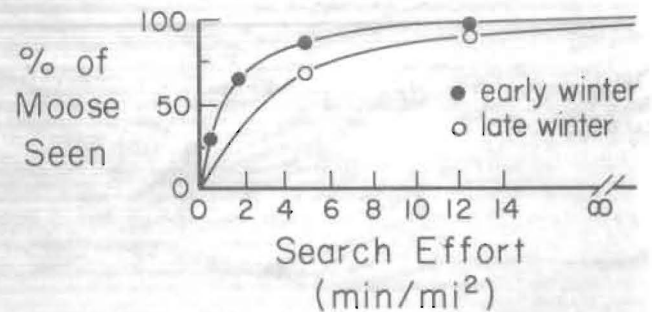


Figure 9. The influence of search effort (min/mi²) on sightability of moose during early winter (Oct-Dec) and late winter (Jan-Apr) aerial surveys.

able time in interior Alaska is 4 min/mi², and sometimes 6 to 8 min/mi² will be required if unusual circumstances occur, e.g., deep snow, which encourages moose to select spruce forest more frequently, or high moose density (greater than 4 moose/mi² in a SU), which requires substantial time to fly circles around each group of moose. Sightability will vary among areas of North America, and corresponding adjustments in search effort will be required. Search time must increase as the canopy increases in height and density. Examples of habitat found in interior Alaska are included (Figs. 10-14) for use in comparing habitats of other areas.

Appropriate search time per SU is calculated by estimating area in mi² from a map and multiplying by 4.5 min/mi² (or a greater value if required) plus 1 min of circling per group expected in the SU. Therefore, a 12 mi² low-density SU where no moose were expected would require 54 min to search at 4.5 min/mi². A 12 mi² high-density SU with eight groups of moose expected would require 62 min to search at a base rate of 4.5 min/mi². Practice is required to gauge the flight pattern to complete the survey in the prescribed time. Both pilots and observers should practice prior to surveys.



Figure 10. Shrub-dominated alpine habitat in interior Alaska.

3.6.3.2 Flight pattern

The major determinant of search pattern in the SU is topography. Minor variation in search intensity is achieved by altering the distance between flight lines and varying the number of circles made off flight lines.

Flat Land.—Parallel transects are flown at 0.25-mi intervals to achieve approximately 4.5 min/mi^2 of search effort when few moose are present. Fly at 60 to 70 mph and 200 to 300 ft above ground. Height should be greatest when flying

over tall timber. Fly transects on a compass heading parallel to the short axis of the SU. This allows better orientation and minimizes missing or duplicating areas. Estimate the number of transects to be flown by multiplying SU length in miles by 4. Make sure no fewer than this number are flown (Fig. 15, SU1). While the plane turns into another transect, mark the approximate location of the transect on the map. This helps assess transect intervals. Mark the location of moose groups on the map if time permits. Fly one or more



Figure 11. Shrub-dominated burn in interior Alaska.

circles around each group of moose or single moose to look for more moose and to classify moose by sex and age.

Hills And Mountains.—The flight path, flown at 60 to 75 mph, generally follows topographic features and consists of contour routes, circles, and flights along ridges and creeks. The interval between flight lines is less than or equal to 0.25 mi. Circles are very effective at heads of valleys and over ends of ridges (Fig. 15, SU2). Concentrate search effort from one side of the plane; generally the down slope side of

the plane is preferred because it provides a more vertical view of trees and the best view of heads of valleys during turns. Occasionally, however, viewing the upslope side will be more effective, e.g. very steep slopes and the ends of gently rounded ridges. The height above ground varies because you are viewing slopes. Fly circles over *all* groups of moose or single moose.

The pilot's main responsibilities are to fly the appropriate search pattern and to keep the plane oriented with respect to



Figure 12. Shrub-dominated forest in interior Alaska.

SU boundaries. Pilots must have a map showing SU boundaries. Expect pilots to also look for moose when they can. Most survey pilots spot many moose.

3.6.3.3 Timing of sample unit searches

Generally, begin searching SUs the day after they are stratified. If you are confident few SU boundaries will be altered during stratification, SU searches and stratification

can begin on the same day—but in different portions of the survey area. Keep planes well separated to avoid midair collisions! If SUs are searched before stratification, the stratification crew must not be told the results until the SU is stratified. When the stratification crew changes boundaries of a SU that was previously surveyed, those survey data should be discarded and the new SU of the same number should be surveyed. This is the price paid for surveying before stratification.



Figure 13. Deciduous tree-dominated forest in interior Alaska.

3.6.4 Late Winter Survey Methods (Jan-Apr)

Because moose move to areas with taller and denser forest canopies and occur in smaller groups during late winter compared to early winter, moose become more difficult to see during late winter (Fig. 10) (Lynch 1975, Novak 1981). This poses a serious problem because making an unbiased and precise estimate of sightability becomes increasingly difficult as sightability declines. Greater variation in sightability among habitat types affects bias and precision of the

estimated SCF (sightability correction factor). The problem is not easily overcome, but increasing search effort and using smaller SUs can help.

The degree of change in sightability will depend on the types of habitat available to moose. The simplest case is in areas having little or no coniferous forest, e.g., the extreme northern and northwestern coast of Alaska, and northern Canada. High sightability can be obtained with little or no increase in search effort; therefore, use procedures de-



Figure 14. Spruce-dominated forest in interior Alaska.

scribed for early winter surveys (Section 3.6.5).

Areas with coniferous forest are more difficult to survey. The ability to precisely estimate sightability with minimum bias deteriorates rapidly as the coniferous canopy increases in height and density. The result is an underestimate of moose abundance, a widening CI, and a CI that has a lower than specified probability of containing the actual number of moose because the CI is centered on a biased estimate. Estimates made with these conditions will not be as useful

as ones obtained when sightability is high. However, moose occur in expansive coniferous forests in portions of North America, and one must either work with this constraint or make no population estimates. So we offer a few brief suggestions on late winter surveys in areas containing coniferous forest. The approach varies with the openness of the coniferous canopy; we assume a late winter use of the coniferous forest by moose.

Closed Canopy.—Estimating numbers of moose in areas

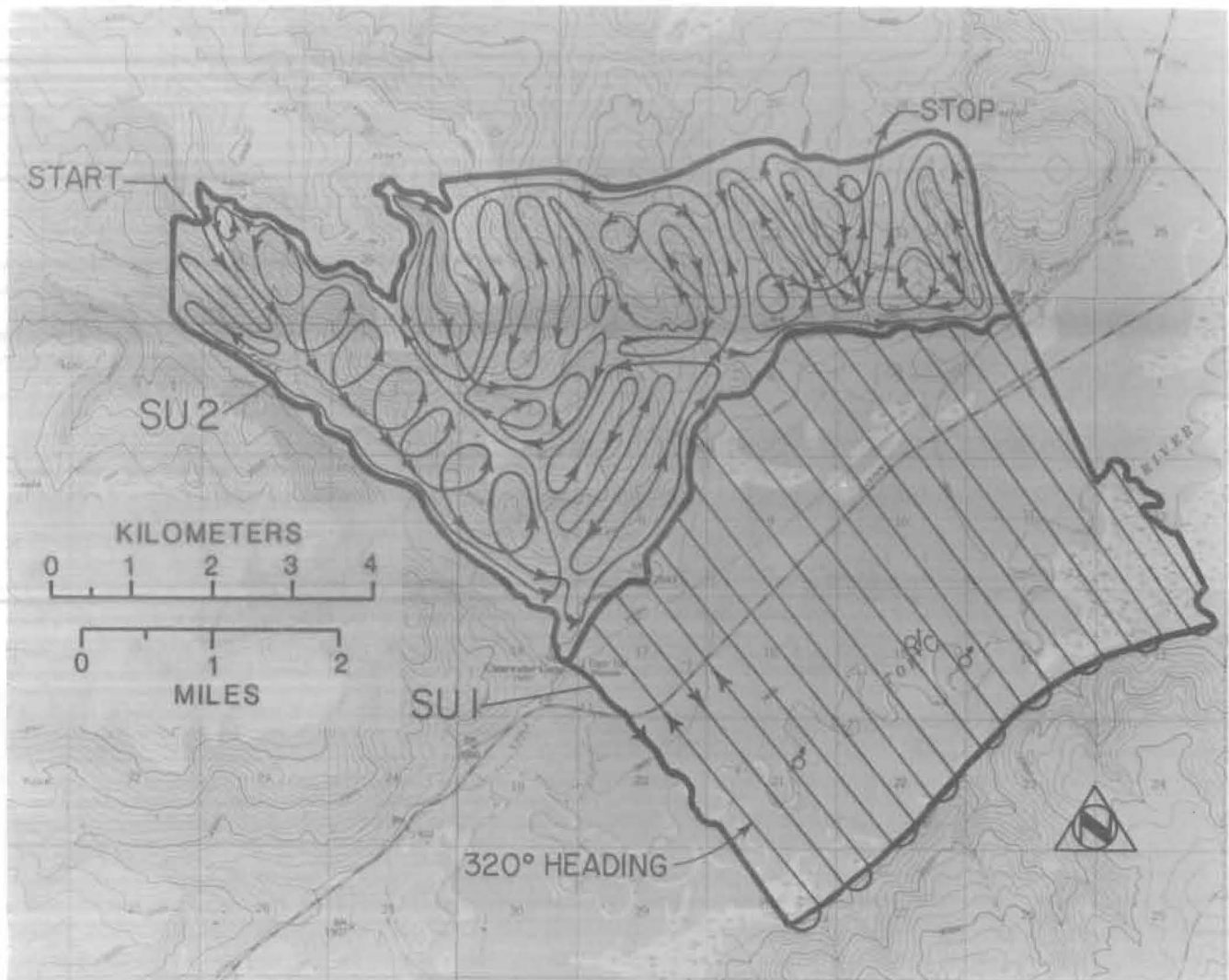


Figure 15. Example of flight path while searching sample units (SUs) in flat land, hills, and mountains. The flight path in the flats is a set of transects spaced 0.25 mi apart. The flight path in the hills and mountains generally follows contours and includes circles along ridges and creeks.

dominated by closed canopy coniferous forest is futile. Sightability of moose is simply too low.

Semi-Open Canopy.—This type of vegetation (Fig. 16) will require a high search intensity (probably greater than or equal to 30 min/mi²) and small SUs of 1 to 3 mi². Unfortunately, an unbiased and precise estimate of sightability probably cannot be achieved through intensive searches. A correction factor for missed moose must be developed independent of the survey method by using radio-collared moose. This is expensive, site-specific information.

Open Canopy.—This is the only coniferous canopy type in which we are optimistic about obtaining late winter population estimates (Fig. 12-14). This canopy is similar to the type in which we conducted our experimental sightability studies. SUs of 8 to 12 mi² and a search intensity of at least 6 to 8 min/mi² on the initial search are recommended. An observed SCF (Section 3.6.5.1) can be estimated from a

more intensive search immediately following the standard search (Section 3.6.5.2). However, an unbiased overall SCF cannot be estimated by this 2-stage search method because a large percentage of the moose are not observed during the more intensive search. Therefore, the population estimator will underestimate abundance unless an additional correction factor can be independently estimated using radio-collared moose.

If late winter population estimates in areas with coniferous forest are generally low because of the inability to estimate an appropriate SCF, can these low estimates at least provide an accurate population trend? Probably not, and the answer becomes more emphatically *no* as sightability deteriorates. The two principal reasons are that large unknown biases cannot be held constant among years and precision of the estimated SCF will be poor; therefore, the population estimate will have a large variance. In general, precision



Figure 16. Semi-open coniferous canopies, like this example, require a high search intensity to see a high percentage of moose present.

declines as sightability declines. Trends can only be determined from precise estimates corrected for sightability or from precise estimates where sightability error is held con-

stant; during late winter or where moose extensively use coniferous forest, neither condition can be accomplished well.

3.6.5 Estimating Sightability of Moose

3.6.5.1 Defining and applying sightability estimates

Sightability is defined as the percentage of moose seen in the area searched (Caughley 1974), and a SCF must be estimated to produce an estimate of population size with minimum sightability bias. The estimator of population size is the following:

$$\text{no. of moose} = \text{no. moose estimated from standard search} \times \text{SCF.}$$

The SCF is the product of an observed SCF (SCF_o) and a correction factor constant (SCF_c) for moose missed while estimating SCF_o . SCF_c is a constant value for a set of conditions (e.g., location, habitat, season), and its value is derived experimentally using radio-collared moose.

For an early winter survey where sightability is high, the SCF_o is estimated by surveying moose in a 2-mi^2 portion of a SU during the standard search (4 to 6 min/ mi^2) and immediately resurveying the 2 mi^2 with an intensive search of 12 min/ mi^2 . The SCF_o is calculated as follows:

$$\text{SCF}_o = \frac{\text{no. moose seen during intensive search}}{\text{no. moose seen during standard search}} + \text{correction for small-sample bias.}$$

Detailed formulae for calculating SCF_o and $V(\text{SCF}_o)$ are in Section 3.6.5.3.

We used radio-collared moose to estimate the bias associated with the SCF_o , i.e., SCF_c . Our experiments showed that during early winter in interior Alaska, 98% of the moose were seen with intensive searches averaging 12 min/ mi^2 . Therefore, $\text{SCF}_c = 100 \div 98 = 1.02$, and the $\text{SCF} = \text{SCF}_o \times \text{SCF}_c = \text{SCF}_o \times 1.02$. Using the same survey conditions but in late winter, sightability of radio-collared moose dropped to 89% producing a $\text{SCF}_c = 100 \div 89 = 1.13$. These are site-specific SCF_c s.

Estimating a SCF for late winter or anytime the forest canopy is dense and tall is difficult because many moose may be missed during intensive searches. Depending on the canopy cover, the standard search intensity in late winter may have to equal or exceed that of an early winter intensive search. Several options exist for estimating the SCF in late winter. First, as in early winter, estimate a SCF_o during the survey and use an existing estimate for SCF_c if survey conditions are similar to those where the SCF_c was estimated. Second, estimate a SCF_o using a very high search effort for the intensive search (e.g., 30 min/ mi^2) and assume that $\text{SCF} = \text{SCF}_o$. In this case, no estimate of SCF_c exists for the high intensity search. Third, search effort of the standard search equals that of an intensive search; therefore, the $\text{SCF} = \text{SCF}_c$. If habitat and snow conditions were similar to those used to estimate a SCF_c , then use a previously estimated SCF_c . In most cases, however, you will not have an appropriate SCF_c ; therefore, either assume it equals 1.0,

which is clearly an underestimate, or guess based on experience in other areas. Neither option is appealing.

Regardless of how sightability is estimated, when the number of moose seen on an intensive survey is not close to 100%, SCFs are subject to large and unmeasurable errors. Size of the errors directly affects moose population estimates.

3.6.5.2 Survey procedures for estimating sightability in early winter

The SCF_o is calculated from moose seen in 2 mi^2 plots in high and medium strata, assuming the average density observed in each stratum is greater than or equal to 1.0 moose/ mi^2 . No plots are searched in the low stratum because few moose are present, and it is unlikely a moose will occur in a plot. Nothing can be learned about sightability if no moose are present. Our experience shows it is not economically feasible to estimate sightability where density is less than 1.0 moose/ mi^2 nor is it feasible to estimate a SCF for each stratum or for each pilot/observer team. Therefore, a single SCF_o is estimated and applied to the pooled survey data.

Begin the population estimation survey by flying an intensive search plot in every surveyed medium- and high-density SU. You may be able to reduce this rate later in the survey, but it is generally necessary to fly intensive searches in 50 to 100% of the surveyed medium- and high-density SUs to achieve a precise population estimate. The number of intensive survey plots is determined by the optimal allocation procedure (Section 3.10.3) and is directly related to the SCF_o and variance of SCF_o . Intensive searches are initially flown in every medium- and high-density SUs surveyed because (1) they allow you to assess sightability early in the survey, and (2) the optimal allocation procedures (Section 3.10.3) may require intensive searches in each medium- and high-density SU.

To select the portion of the SU to search intensively:

1. Divide each medium- and high-density SU into roughly four quarters on the topographic map and randomly select one quarter from each SU.
2. Draw a plot of approximately 2 mi^2 within the selected quarter. Plot boundaries should be terrain features identifiable on the map (Fig. 17). The search time required is approximately 0.5 hours.
3. If intensive search plots are flown in less than 100% of medium- and high-density SUs, randomly select those SUs that will receive plots.

Identify exact plot boundaries from the air immediately before beginning the standard search of the SU if plot boundaries are difficult to identify. Moose observed during the standard search must be mapped accurately with reference to the plot boundaries. If possible, survey the SU so that the 2-mi^2 sightability plot is flown near the end of the standard search. Immediately upon completion of the stand-

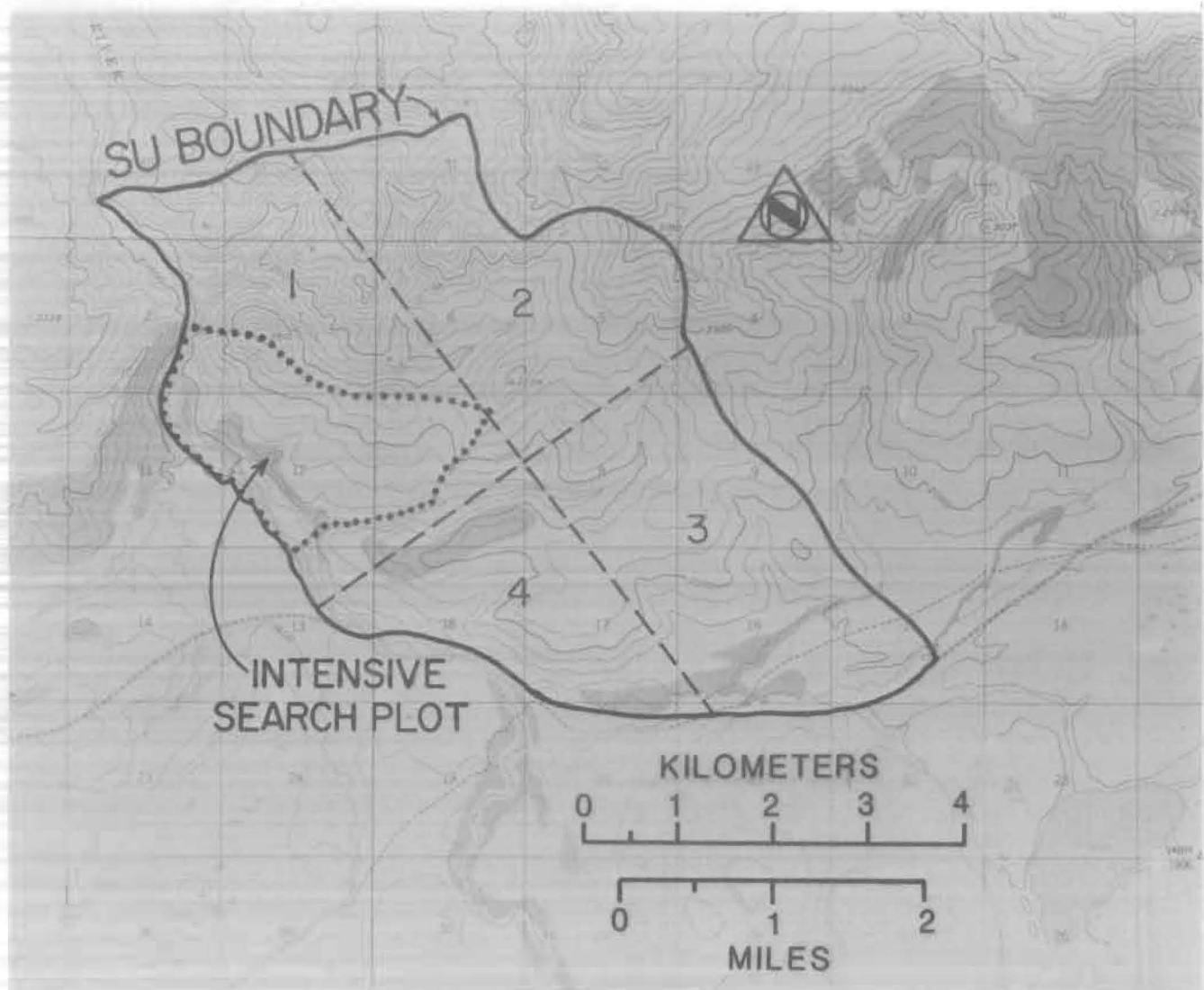


Figure 17. Example of a sample unit (SU) divided into 4 quarters for the purpose of randomly selecting the quarter that will contain the 2-mi² intensive search plot. Quarter number 1 was selected, and the plot was drawn as shown.

ard search of the SU, intensively search the plot a minimum of 12 min/mi² and record the number of moose seen in the plot during the intensive search. This procedure reduces the time between the two searches and the time moose have to redistribute themselves. Occasionally, identifiable groups of moose will move into or out of the plot between the two searches. If moose move into the plot, do not record them during the intensive search. If moose move out of the plot and are seen during the intensive search, record them on both searches. If moose move out of the plot and are not seen on the intensive search (but the exit was confirmed by tracks in snow), delete the observation from the standard search for sightability calculations. Moose not observed during intensive searches are compensated for by the SCF_c.

Do not search the plot with different effort during the standard search than is normally used for standard searches. To help ensure standard search intensity, do not inform the

pilot that a plot will be resurveyed until it is time for the high-intensity search. However, the observer must know the boundaries of the plot during the standard search so that moose can accurately be mapped and tallied. The observer must also guard against changing the effectiveness of his search in the sightability plot during the standard survey.

Search intensities of greater than or equal to 12 min/mi² use a different flight pattern than those described in Section 3.6.3 for low-intensity searches.

Flat Land.—A series of slightly overlapping circles or ovals are flown (Fig. 18) at 200 to 300 feet above the ground and at 60 to 70 mph. The radii of circles are 0.1 to 0.3 mi, and the radii should decrease as canopy height and density increase. Observations are made from the low wing side of the plane.

Hills and Mountains.—Fly close contours and make frequent circles over the heads of canyons and over the ends of

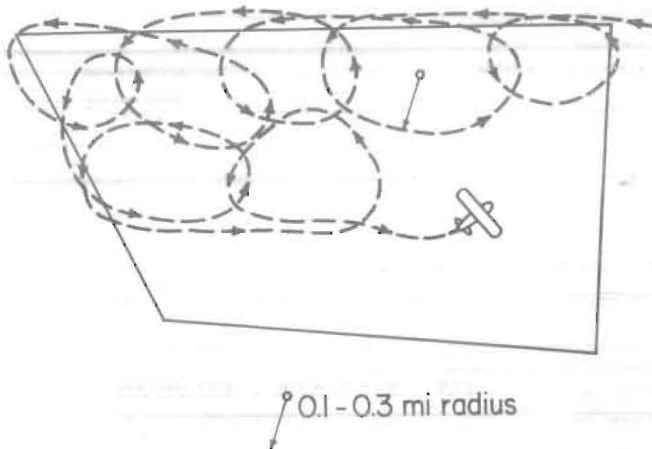


Figure 18. Flight pattern used over flat terrain during intensive searches of 2-mi² sightability plots.

ridges at 60 to 75 mph. This search pattern is similar to that used for the standard search of SUs (Fig. 15, SU2) except contours are closer and circling is more frequent. Height above the ground is variable because you are looking at slopes.

The SCF_o should be calculated daily, and we recommend maintaining a mean value of less than or equal to 1.15. If SCF_o is greater than 1.15, increase the standard search effort in future SUs. If standard search effort needs to be increased, the decision to do so should be made as early in the survey as possible. Changes in standard search effort will increase the variance of the total population estimate, so it is necessary to find and maintain an acceptable level of effort as early as possible.

SCF_os as low as 1.03 have been achieved in shrub-dominated survey areas in Alaska, but the expense required to produce a low SCF_o in areas dominated by coniferous forest is prohibitive.

3.6.5.3 Estimating the observed sightability correction factor and its sampling variance

The following symbols will be used for the calculation of SCF_o and V(SCF_o):

- n_o = the number of 2-mi² plots surveyed with an intensive search
- u_k = the number of moose seen during the intensive search in the k th sightability plot; $k=1 \dots n_o$
- v_k = the number of moose seen during the standard search in the k th sightability plot; $k=1 \dots n_o$.

Calculate the SCF_o as follows:

$$SCF_o = \frac{\text{no. moose seen during intensive search}}{\text{no. moose seen during standard search}} + \text{correction for small-sample bias}$$

or

$$SCF_o = \frac{\sum_k u_k}{\sum_k v_k} + \frac{n_o s_{uv}^2}{(\sum_k v_k)^2} - \frac{n_o (\sum_k u_k) s_v^2}{(\sum_k v_k)^3}$$

where

$$s_{uv}^2 = \frac{\sum_k u_k v_k}{n_o - 1} - \frac{\sum_k u_k (\sum_k v_k)}{n_o (n_o - 1)}$$

and

$$s_v^2 = \frac{\sum_k v_k^2}{n_o - 1} - \frac{(\sum_k v_k)^2}{n_o (n_o - 1)}$$

The sampling variance of SCF_o is

$$V(SCF_o) = \frac{n_o}{(\sum_k v_k)^2} (s_{qs}^2)$$

where

$$s_{qs}^2 = \frac{\sum_k u_k^2 - 2(SCF_o) \sum_k u_k v_k + SCF_o^2 \cdot \sum_k v_k^2}{n_o - 1}$$

The formula for estimating the sightability correction factor is a ratio formula with a correction for small-sample bias. We use the bias correction because we found that the empirical distributions used in our simulations for sightability caused the standard ratio formula to yield estimates with a substantial small-sample bias. The correction for small-sample bias is based on Cochran's (1977) discussion of bias in ratio estimators. Our simulation studies indicated that, in addition to reducing bias, the corrected formula consistently yields an estimator with a smaller sampling variance than the standard formula. For small sample sizes (less than or equal to 5) the reduction in variance may be greater than 40%, whereas with large sample sizes, the variance reduction is negligible.

3.6.5.4 Example: calculating the observed sightability correction factor and its sampling variance

The HP 97 calculator has been programmed to calculate SCF_o and V(SCF_o) as part of the program designed to calculate the population estimate (Section 3.9).

Table 6. Sightability data for 10 sample units in the fictitious Square Mountain survey area.

	Number moose seen in 2-mi ² sightability plot										Total moose seen during search
Standard search effort (v_k)	0	3	14	5	0	1	2	7	8	6	46
Intensive search effort (u_k)	0	3	15	6	1	1	2	7	8	7	50

The following example is a step-by-step guide for the hand calculation of SCF_o and $V(SCF_o)$. The function of this example and others in the manual is to demonstrate to the reader how to correctly use the formulae. Other data can then be substituted for the example data with the assurance that calculations are correct. Assume that the data used in the calculations were collected during intensive searches of plots in 10 SUs during the Square Mountain survey (Table 6). When performing these calculations, it is important to use the number of decimal places indicated in this example to reduce problems with rounding error. Refer to Section 3.6.5.3 for formulae while working through calculations in this section.

SCF_o .—First solve for s_{uv}^2 and s_v^2 .

$$s_{uv}^2 = \frac{409}{10 - 1} - \frac{50 \times 46}{10(10 - 1)}$$

$$= 19.888888.$$

$$s_v^2 = \frac{384}{10 - 1} - \frac{(46)^2}{10(10 - 1)}$$

$$= \frac{384}{9} - \frac{2116}{90}$$

$$= 19.155556.$$

Use the values of s_{uv}^2 and s_v^2 to solve for SCF_o .

$$SCF_o = \frac{50 \text{ moose}}{46 \text{ moose}} + \frac{10 \times 19.888888}{46^2} - \frac{10 \times 50 \times 19.155556}{46^3}$$

$$= 1.086957 + 0.093993 - 0.098399$$

$$= 1.082551.$$

$V(SCF_o)$.—First solve for s_{qs}^2 .

$$s_{qs}^2 = \frac{438 - 885.526718 + 450.016001}{10 - 1}$$

$$= 0.276587.$$

Use the value of s_{qs}^2 to solve for $V(SCF_o)$.

$$V(SCF_o) = \frac{10}{46^2} \times 0.276587$$

$$= 0.001307.$$

3.6.5.5 Estimating sightability in low-density populations

Sightability estimates, as described in Section 3.6.5.1, are not economically feasible in low-density moose populations. Put simply, one cannot afford the time or dollars to sample the very large number of plots required to precisely estimate the SCF_o . The probability of moose occurring in a 2-mi² plot is low, and moose must be present or sightability cannot be estimated. This is the same logic used to omit sightability plots from the low-density stratum in high-density populations.

Two options exist for estimating the SCF_o for low-density populations. First, sightability estimates made in higher density populations, but under similar habitat and snow conditions, can be applied to low-density populations. However, applying a SCF_o from similar, nearby areas is risky. In Alaska, early winter SCFs (i.e., $SCF_o \times SCF_c$) from four widely differing survey areas ranged from 1.05 to 1.18 when survey techniques described in this manual were used (Table 7). These data may reflect the range of potential errors. To apply SCFs from other areas, select SCFs with the most comparable survey conditions. If more than one comparable area exists, use the mean SCF or (\overline{SCF}) , i.e., sum of SCFs \div no. of SCFs; the corresponding variance is approximated as

$$V(\overline{SCF_o}) = \frac{\text{mean variance of the } SCF_o \text{ s}}{\text{no. of } SCF_o \text{ s}}$$

Table 7. Observed sightability correction factor (SCF_o), sightability correction factor constant (SCF_c), variance [$V(SCF_o)$], and degrees of freedom of SCF_o [v_s] estimated during moose surveys in Alaska. Standard search effort averaged about 4 to 5 min/mi² except where noted.

Season and survey area	SCF_o	SCF_c	$V(SCF_o)$	v_s	Dominant habitat	Terrain
Early winter (Oct-Nov)						
Upper Susitna	1.027535	1.02	0.000411	9	Subalpine shrub, some spruce forest	Mountains
Upper Nowitna	1.069074	1.02	0.001379	12	Mixed forest, shrub-dominated high ridges and a few small burns	Hills
Tanana Flats	1.148780 ^a	1.02	0.004061	30	Mixed forest interspersed with large areas of early seral shrubs	Lowland flats
Lower Nowitna	1.155249	1.02	0.006667	11	Mixed forest, shrubs along ponds and streams, some lowland bogs	Hills and lowland flats
Late winter (Feb)						
Alaska Peninsula	1.082446	1.02	0.002212	10	Shrub dominated, no coniferous forest	Flats, hills, and mountains
Nushagak	1.198800	1.13	0.008020	7	Mixed forest with shrubs along streams and in the highlands	Flats, hills, and mountains

^a Standard search intensity averaged 6 min/mi².

$$\begin{aligned} &= \frac{\sum_1 [V(SCF_o)]_1 \div n}{n} \\ &= \frac{\bar{V}(SCF_o)}{n} \end{aligned}$$

ance of 0.00401 and 1.14 with variance of 0.00602. The mean values are calculated as

$$\overline{SCF} = \frac{1.10 + 1.14}{2} = 1.12$$

and

$$V(\overline{SCF_o}) = \frac{0.01003}{2} \times \frac{1}{2} = 0.00251.$$

where n is the number of SCFs used to estimate the mean SCF and $i = 1 \dots n$.

For example, assume the following two SCFs are appropriate to apply to a low-density survey area: 1.10 with vari-

The \overline{SCF} and $V(\overline{SCF}_0)$ are used in the conventional manner for estimating population size and CI, respectively (see Sections 3.7.3, 3.7.4, and 3.7.5).

The second approach is to intensively search only those plots in which moose were observed during the standard search. Plots in low-density areas must be increased in size to increase the probability of plots containing moose. We recommend 4-mi² plots, i.e., double the size normally used. Using this method, time and dollars are spent intensively searching only plots where there is some known sightability information. The \overline{SCF}_0 and $V(\overline{SCF}_0)$ are calculated as in Section 3.6.5.3. However, these formulae are biased estimators of \overline{SCF}_0 and $V(\overline{SCF}_0)$, with each parameter being underestimated. Therefore, this procedure should only be used where moose densities are too low to use the unbiased method described in Section 3.6.5.1.

Our experience indicates the bias for the \overline{SCF}_0 will be small because sightability during the standard survey is high (Table 7). Calculating biased \overline{SCF}_0 s for six surveys in Table 7 reduced the estimated mean \overline{SCF}_0 by only 1%. However, the mean $V(\overline{SCF}_0)$ for these six estimates declined by 27%, resulting in CIs being underestimated by an average of 15%. Because of the small bias, this method is preferred to the first option, unless you are confident that a \overline{SCF}_0 estimated in other areas is an appropriate substitute.

3.6.6 Recording Survey Observations

3.6.6.1 Recording data for standard searches of sample units

All data are recorded on Form 3. Routine data are recorded at the top. Only a few items require explanations.

Habitat descriptions for SUs are useful if you are interested in correlating habitat with moose density, sex and age composition, or sightability. You may have your own habitat classification system. We classify dominant habitat in the SU as one of two major types (shrub-dominated or forest-shrub mixture), each of which are further subdivided as follows:

1. Shrub-dominated habitat (equal to or greater than 80% shrub cover)
 - a. Recent burn (Fig. 11)
 - b. Subalpine (Fig. 12)
2. Forest-shrub habitat (less than 80% shrub cover)
 - a. Shrub-dominated forest (50 to 80% shrub)(Fig. 12)
 - b. Deciduous tree-dominated forest (greater than 50% forest)(Fig. 13)
 - c. Spruce-dominated forest (greater than 50% forest)(Fig. 14).

Snow conditions listed on Form 3 are defined in Section 3.6.2.

Sex and age composition of moose in each group is recorded on a single line of Form 3. Three categories of bulls

are identified based on antler shape and size: yearlings, medium bulls (greater than yearlings but less than 50 inches antler spread), and large bulls (equal to or greater than 50-inch antler spread). Substitute categories that may be appropriate for your studies. Cow and calf designations are self-explanatory. Groups of moose seen in the intensive search plot during the standard search must be checked off (✓) on the form during the standard search so that there is a clear record of moose seen during the standard search.

Moose behavior data can be recorded on Form 3 if desired. Activity of moose (standing or lying) can be indicated by S or L below the number of moose recorded in a sex-age category (e.g., 4/L).

Habitat use by moose is easily recorded on a check list for each group of moose (Form 3). Any habitat classification system familiar to the observer will work, so long as it is simple. We use the seven categories on Form 3: herbaceous (H), low shrub (LS) is less than 2 m tall, tall shrub (TS) is equal to or greater than 2 m tall, deciduous forest (D), sparse spruce forest (SS), spruce forest (S), and larch forest (L).

Collecting behavior and habitat data takes time that could be spent looking for moose and is of value only if there is a planned use for the data. A tape recorder could be substituted for the form, but mechanical failures can cost time and money.

3.6.6.2 Recording data for intensively searched plots

Record data from intensive searches on a separate copy of Form 3. To distinguish intensive data from standard searches, check (✓) the box labeled intensive search on the form. Clearly mark moose or groups of moose not seen during standard searches with "NEW." Occasionally you may miss a moose on the intensive search that was seen on the standard search. Try to find the reason—was the moose missed or did it leave the area? Make notes if there are problems, e.g., a moose seen on the standard search walked out, or a new moose walked in between the standard and intensive search.

Keep complete records of moose seen on the standard and intensive search if the \overline{SCF} is to be accurate. Check all forms for completeness while flying to the next SU.

3.6.6.3 Daily summary of survey data

At the conclusion of each day of surveying, transfer SU data from Form 3 to Form 4, which was designed to summarize SU data by stratum (see Appendix 2 for blank form). Daily summaries will allow efficient daily calculation of the \overline{SCF}_0 and population estimate.

3.7 CALCULATING THE POPULATION ESTIMATE AND CONFIDENCE INTERVAL

Calculation of the total population estimate involves estimating the observable moose population, correcting it for

Game Management Unit(s)	1	Subunit(s)	A
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Source: *U.S. Census Bureau, Bureau of Economic Analysis, "GDP by State and Selected Regions, 1997-2000,"* <http://www.bea.gov/states/gdp.htm>.

[illegible]

moose not seen, and calculating the precision of the total estimate. The calculations are mostly arithmetic and basic statistics and can be performed on a hand calculator. These calculations are divided below into five major steps.

3.7.1 Step 1.—Calculating the Observable Stratum Population Estimate and Its Sampling Variance

The observed stratum population is the number of moose that could have been seen if the entire stratum had been searched with the standard search effort (e.g., 4 to 6 min/mi² in early winter).

3.7.1.1 Definition of symbols

A_i = area (mi²) of a particular stratum i = "h", "m", "l"

y_j = number of observed moose in the j th SU

x_j = number of mi² in the j th SU

\bar{x}_i = mean mi² of all SUs surveyed in the i th stratum

n_i = number of SUs surveyed in the i th stratum

N_i = total number of SUs in the i th stratum

d_i = observable density (moose/mi²) in the i th stratum

\hat{T}_i = observable population estimate in the i th stratum

$V(\hat{T}_i)$ = sampling variance of observable population estimate in the i th stratum.

3.7.1.2 Observable stratum population estimate (\hat{T}_i)

The observable stratum population estimate is calculated as

$$\hat{T}_i = \text{density of moose} \times \text{area of stratum}$$

or

$$\hat{T}_i = d_i A_i.$$

Moose density in a stratum (moose/mi²) is calculated as

$$d_i = \frac{\text{total no. moose seen in all surveyed SUs}}{\text{total surface area of all surveyed SUs (mi}^2\text{)}}$$

or

$$d_i = \frac{\sum_j y_j}{\sum_j x_j}.$$

Area of a stratum (A_i) is calculated by summing the area of each SU in the stratum. The area of each SU (x_j) should be measured with a computer-driven digitizer or a polar compensating planimeter (purchased at graphics shops for about \$200.00). A preliminary estimate of area for each SU is made from a map by counting the number of 1-mi² blocks within a SU plus the partial blocks along the SU boundaries.

3.7.1.3 Sampling variance of the stratum population estimate [$V(\hat{T}_i)$]

$$V(\hat{T}_i) = A_i^2 \left[\frac{1}{\bar{x}_i^2} \cdot \frac{s_{qi}^2}{n_i} \left(1 - \frac{n_i}{N_i} \right) \right].$$

To estimate $V(\hat{T}_i)$, calculate the stratum sample variance (s_{qi}^2) as

$$s_{qi}^2 = \frac{\sum_j y_j^2 - 2d_i \sum_j x_j y_j + d_i^2 \sum_j x_j^2}{n_i - 1}.$$

Then insert the value of s_{qi}^2 into the formula and compute $V(\hat{T}_i)$.

Sample variance measures the deviation in number of moose counted in a SU from the number expected based on its size. The stratum sampling variance formula also contains a finite population correction factor $(1 - n_i/N_i)$, which reduces the variance of the estimate as the number of SUs surveyed increases.

3.7.2 Step 2.—Calculating the Observable Population Estimate and Its Sampling Variance for the Survey Area

The observable population estimate is the number of moose that could have been seen if the entire survey area had been searched with the standard search effort. It is uncorrected for sightability.

3.7.2.1 Observable population estimate (\hat{T}_o)

$$\hat{T}_o = \Sigma \text{ observable strata population estimates}$$

or

$$\hat{T}_o = \hat{T}_h + \hat{T}_m + \hat{T}_l$$

where h, m, and l indicate high-, medium-, and low-density strata, respectively.

3.7.2.2 Sampling variance of observable population estimate [$V(\hat{T}_o)$]

$$V(\hat{T}_o) = \Sigma \text{ variances of observable strata population estimates}$$

or

$$V(\hat{T}_o) = V(\hat{T}_h) + V(\hat{T}_m) + V(\hat{T}_l)$$

where h, m, and l indicate high-, medium-, and low-density strata, respectively.

3.7.2.3 Degrees of freedom (ν_o) for the observable population estimate

$$\nu_o = \frac{[V(\hat{T}_o)]^2}{\frac{[V(\hat{T}_h)]^2}{n_h - 1} + \frac{[V(\hat{T}_m)]^2}{n_m - 1} + \frac{[V(\hat{T}_l)]^2}{n_l - 1}}$$

where n_h , n_m , and n_l are the number of SUs flown in high-, medium-, and low-density strata, respectively (Satterthwaite 1946).

3.7.3 Step 3.—Calculating the Expanded Population Estimate and Its Sampling Variance

The observable population estimate corrected for observed sightability is referred to as the expanded population estimate. A new variance is also calculated that combines the sampling variance of the observed sightability correction factor with the sampling variance of the observable population estimate.

3.7.3.1 Definition of symbols

- \hat{T}_e = expanded population estimate for the entire survey area
- SCF_o = observed sightability correction factor (defined in Section 3.6.5.1)
- $V(SCF_o)$ = sampling variance of the observed sightability correction factor (defined in Section 3.6.5.3)
- $V(\hat{T}_e)$ = sampling variance of the expanded population estimate
- n_o = number of 2-mi² plots resurveyed with an intensive search for estimating SCF_o
- ν_e = degrees of freedom for the \hat{T}_e
- ν_o = degrees of freedom for the observable population estimate (\hat{T}_o) (defined in Section 3.7.2.1)
- ν_s = degrees of freedom for SCF_o .

3.7.3.2 Expanded population estimate (\hat{T}_e)

$$\hat{T}_e = \begin{array}{c} \text{observable} \\ \text{population} \\ \text{estimate} \end{array} \times \begin{array}{c} \text{observed sightability} \\ \text{correction factor} \end{array}$$

or

$$\hat{T}_e = \hat{T}_o \cdot SCF_o.$$

3.7.3.3 Sampling variance of the expanded population estimate [$V(\hat{T}_e)$]

A sampling variance approximation [$V(\hat{T}_e)$] for the expanded population estimate combines sampling variance of

the observable population estimates [$V(\hat{T}_o)$] with the sampling variance of the observed sightability correction factor [$V(SCF_o)$] (Goodman 1960) as follows:

$$V(\hat{T}_e) = SCF_o^2 [V(\hat{T}_o)] + \hat{T}_o^2 [V(SCF_o)] - V(SCF_o)[V(\hat{T}_o)].$$

For low-density populations where SCF_o cannot be estimated, substitute \bar{SCF} and $V(\bar{SCF})$ for SCF and $V(SCF_o)$, respectively (see Section 3.6.5.5).

The formula for the sampling variance of the expanded population estimate is based on the theoretical assumption that observable moose and the sightability correction are estimated independently. This is clearly not the case in our sampling methodology. We tested the formula using computer simulation under two sets of conditions. For the first condition, the sightability of an individual moose was independent of moose density. For the second condition, the sightability of an individual moose was dependent upon group size in the population. Specifically, if the probability of an individual moose (group size = 1) being seen with regular search effort was p , we simulated the probability of a moose being missed at regular search effort for groups of size 1, 2, 3, 4... as being $(1 - p)$, $(1 - p)$, $(1 - p)^2$, $(1 - p)^3$ Group size distribution in sample units was based on unpublished data. We believe that the two conditions represent the opposite extremes in possible relationships between sightability and moose density. We found that the sampling variance formula provided a very good approximation of variance for our methodology under both sets of conditions, despite the lack of independence of the estimates of observable moose and sightability correction factor. While we recommend the formula for our methodology, we do not recommend the application of the formula for the product of other nonindependent estimators.

3.7.3.4 Degrees of freedom (ν_e)

The number of degrees of freedom for our observed sightability correction factor (SCF_o) is

$$\nu_s = n_o - 1.$$

Then, the number of degrees of freedom for our expanded population estimate (\hat{T}_e) is the smaller of the two values ν_o and ν_s

$$\nu_e = \text{minimum of } [\nu_o, \nu_s].$$

3.7.4 Step 4.—Calculating the Total Population Estimate and Its Sampling Variance

3.7.4.1 Total population estimate (\hat{T})

$$\hat{T} = \begin{array}{c} \text{expanded} \\ \text{population} \\ \text{estimate} \end{array} \times \begin{array}{c} \text{sightability correction} \\ \text{factor constant} \end{array}$$

or

$$\hat{T} = \hat{T}_e \cdot SCF_c.$$

3.7.4.2 Sampling variance of total population estimate $[V(\hat{T})]$

$$V(\hat{T}) = V(\hat{T}_e) \cdot SCF_e^2$$

3.7.5 Step 5.—Calculating the Confidence Interval of the Total Population Estimate

3.7.5.1 Definition of symbols

CI = confidence interval

CL_u = upper confidence limit

CL_l = lower confidence limit

t = Student's t -statistic (discussed in Section 2)

$1 - \alpha$ = specified probability for the CI

v_e = degrees of freedom (defined in Section 3.7.3.4).

3.7.5.2 Confidence interval

$$CI = \text{total population estimate} \pm t_{\alpha, v_e} \sqrt{\text{variance of total population estimate}}$$

or

$$CI = \hat{T} \pm t_{\alpha, v_e} \sqrt{V(\hat{T})}$$

The degrees of freedom (v_e) were calculated in Section 3.7.3.4. Student's t -values for confidence intervals of specified confidence levels ($1 - \alpha$) are found in Table 8.

The CI is commonly expressed as a percentage of the total population estimate because the percentage clearly shows the relative CI width (precision). This expression of the CI is calculated as

$$CI \text{ as } \pm \% \text{ of population estimate} =$$

$$\frac{\left(\begin{array}{c} \text{total} \\ \text{population} \\ \text{estimate} \end{array} - \begin{array}{c} \text{lower} \\ \text{confidence} \\ \text{limit} \end{array} \right)}{\text{total population estimate}} 100$$

or

$$CI \text{ as } \pm \% \text{ of } \hat{T} = \frac{(\hat{T} - CL_l) 100}{\hat{T}}$$

The final expression is $\hat{T} \pm CI\%$, e.g., 1,000 moose $\pm 20\%$.

The formula for the confidence interval is generally reliable; however, our simulation studies demonstrated certain conditions where it can be inaccurate. This formula is sensitive to the quality of the estimate of SCF. The reason for this is that the type of data in SCF_e estimates does not lend itself to the calculation of confidence intervals using Student's t -values, particularly with small sample sizes. This negative aspect of estimating SCF_e is buffered by the way that the

Table 8. Critical values of Student's t -distribution for confidence intervals (CI), and two-tailed (α) tests.

Degrees of freedom (v)	CI ($1-\alpha$) 80%	90%	95%
$\alpha = .20$.10	.05	
1	3.078 ^a	6.314	12.706
2	1.886	2.920	4.303
3	1.638	2.353	3.182
4	1.533	2.132	2.776
5	1.476	2.015	2.571
6	1.440	1.943	2.447
7	1.415	1.895	2.365
8	1.397	1.860	2.306
9	1.383	1.833	2.262
10	1.372	1.812	2.228
11	1.363	1.796	2.201
12	1.356	1.782	2.179
13	1.350	1.771	2.160
14	1.345	1.761	2.145
15	1.341	1.753	2.131
16	1.337	1.746	2.120
17	1.333	1.740	2.110
18	1.330	1.734	2.101
19	1.328	1.729	2.093
20	1.325	1.725	2.086
21	1.323	1.721	2.080
22	1.321	1.717	2.074
23	1.319	1.714	2.069
24	1.318	1.711	2.064
25	1.316	1.708	2.060
26	1.315	1.706	2.056
27	1.314	1.703	2.052
28	1.313	1.701	2.048
29	1.311	1.699	2.045
30	1.310	1.697	2.042
40	1.303	1.684	2.021
60	1.296	1.671	2.000
120	1.289	1.658	1.980
∞	1.282	1.645	1.960

^a These values were extracted from Appendix Table II of Simpson et al. (1960).

sampling variances of SCF_e and \hat{T}_e are combined to approximate the sampling variance of \hat{T}_e . Under most conditions, this buffering effect is adequate to ensure that the formula for confidence intervals around \hat{T}_e and \hat{T} are accurate.

The formula for the confidence interval around \hat{T} should not be taken literally unless you have performed at least eight intensive searches (n_0 equal to or greater than 8) to estimate sightability. But rather than use this rule of thumb, we recommend that you apply the procedures in Section 3.10.3 which will help allocate sampling effort between standard and intensive searches. If the number of intensive searches is nearly equal to or greater than the optimal allocation, the formula of confidence intervals will be accurate. If the number of intensive searches flown is considerably

Table 9. Data from a population estimation survey in the fictitious Square Mountain survey area.

No. of SUs ^a	Low stratum		Medium stratum		High stratum	
	No. moose seen	SU area (mi ²)	No. moose seen	SU area (mi ²)	No. moose seen	SU area (mi ²)
1	2	12	9	12	49	12
2	2	12	14	12	57	12
3	1	12	22	12	41	12
4	4	12	10	12	23	12
5	1	12	17	12	32	12
6			12	12	6	12
7					35	12
8					35	12
9					19	12
Sample total	10	60	84	72	297	108
Area of <i>i</i> th stratum (<i>A_i</i>)		276		240		156
Total SUs in <i>i</i> th stratum (<i>N_i</i>)		23		20		13

^a SU equals sample unit.

less than the optimal allocation, your confidence intervals may not be accurate.

3.7.6 Summary of Calculations for the Total Population Estimate and Confidence Interval

- Step 1.—Calculate observable stratum population estimates (\hat{T}_i) and sampling variances [$V(\hat{T}_i)$] (Section 3.7.1)
- Step 2.—Calculate observable population estimate (\hat{T}_0), sampling variance [$V(\hat{T}_0)$], and degrees of freedom (ν_0) (Section 3.7.2)
- Step 3.—Calculate expanded population estimate (\hat{T}_e), total sampling variance [$V(\hat{T}_e)$], and degrees of freedom (ν_e) (Section 3.7.3)
- Step 4.—Calculate total population estimate (\hat{T}) (Section 3.7.4)
- Step 5.—Calculate confidence intervals of total population estimate (Section 3.7.5).

3.8 EXAMPLE: CALCULATING THE POPULATION ESTIMATE AND CONFIDENCE INTERVAL

The following example is a step-by-step procedure for calculating a population estimate and confidence interval. Data used in the example are collected from a stratified random sample of the Square Mountain survey area (Table

9). When performing these calculations, it is important to use the number of decimal places indicated in the example to reduce rounding errors. Refer to Section 3.7 for formulae while working through calculations in this section.

3.8.1 Step 1.—Calculating the Observable Strata Population Estimates and Their Sampling Variances

3.8.1.1 Low-density stratum estimates

Density estimate:

$$d_t = \frac{10 \text{ moose observed in low-density SUs}}{60.0 \text{ mi}^2 \text{ surveyed in low-density stratum}} \\ = 0.166667 \text{ moose/mi}^2$$

Observed stratum estimate:

$$\hat{T}_t = (0.166667 \text{ moose/mi}^2)(276 \text{ mi}^2 \text{ in low-density stratum}) \\ = 46 \text{ moose.}$$

Sampling variance estimate:

$$\text{First compute } s_{qt}^2.$$

$$s_{qt}^2 = \frac{26 - 2(0.166667)120 + 20.000160}{5 - 1} = 1.500020.$$

Use the value of s_{qt}^2 to compute $V(\hat{T}_l)$.

$$\begin{aligned} V(\hat{T}_l) &= 276.0^2 \left[\frac{1}{12.00^2} \times \frac{1.500020}{5} \left(1 - \frac{5}{23} \right) \right] \\ &= 76,176.00[0.0069 \times 0.300004(0.782609)] \\ &= 123.405. \end{aligned}$$

3.8.1.2 Medium-density stratum estimates

Density estimate:

$$d_m = 1.166667 \text{ moose/mi}^2.$$

Observed population estimate:

$$\hat{T}_m = 280 \text{ moose}.$$

Sampling variance estimate:

$$s_{qm}^2 = 23.600019$$

$$V(\hat{T}_m) = 1094.285.$$

3.8.1.3 High-density stratum estimates

Density estimate:

$$d_h = 2.750000 \text{ moose/mi}^2.$$

Observed population estimate:

$$\hat{T}_h = 429 \text{ moose}.$$

Sampling variance estimate:

$$s_{qh}^2 = 241.250000$$

$$V(\hat{T}_h) = 1384.962.$$

3.8.2 Step 2.—Calculating the Observable Population Estimate and Its Sampling Variance for Survey Area

Observed population estimate:

$$\hat{T}_o = 46 \text{ in low stratum} + 280 \text{ in medium stratum} + 429 \text{ in high stratum}$$

$$= 755 \text{ observable moose}.$$

Sampling variance estimate:

$$\begin{aligned} V(\hat{T}_o) &= 123.405 \text{ low stratum} + 1094.285 \text{ medium stratum} + 1384.962 \text{ high stratum} \\ &= 2602.652. \end{aligned}$$

Degrees of freedom:

$$\nu_o = \frac{(2602.652)^2}{\frac{(1384.962)^2}{9-1} + \frac{(1094.285)^2}{6-1} + \frac{(123.405)^2}{5-1}} \cong 14.$$

3.8.3 Step 3.—Calculating the Expanded Population Estimate and Its Sampling Variance

For this example, let us assume that 10 (n_o) intensive searches were flown during the Square Mountain survey and resulted in an $SCF_o = 1.08$ and $V(SCF_o) = 0.003400$.

Expanded population estimate:

$$\begin{aligned} \hat{T}_e &= 755 \text{ observable moose} \times 1.08 \text{ observed sightability correction factor} \\ &= 815 \text{ moose}. \end{aligned}$$

Variance estimate:

$$\begin{aligned} V(\hat{T}_e) &= 1.08^2(2602.652) + 755^2(0.003400) \\ &\quad - 0.003400(2602.652) \\ &= 3035.7333 + 1938.0850 - 8.8490 \\ &= 4964.969. \end{aligned}$$

Degrees of freedom:

First, calculate ν_s for SCF_o .

$$\nu_s = 10 - 1 = 9.$$

Degrees of freedom (ν_e) is then used for calculating the CI which is the minimum of ν_o and ν_s :

$$\nu_e = \text{minimum of } [14, 9] = 9.$$

3.8.4 Step 4.—Calculating the Total Population Estimate and Its Sampling Variance

Total population estimate:

$$\hat{T} = 815 \text{ moose} \times 1.02 \text{ SCF}_c = 831 \text{ moose.}$$

Sampling variance estimate:

$$V(\hat{T}) = 1.02^2 \times 4964.969 = 5165.554.$$

3.8.5 Step 5.—Calculating the 90% Confidence Interval for the Total Population Estimate

Confidence interval:

$$\begin{aligned} CI &= 831 \pm 1.833 \sqrt{5165.554} \\ &= 831 \pm 132 \text{ moose.} \end{aligned}$$

Confidence limits:

$$CL_L = 699 \text{ moose}$$

and

$$CL_U = 963 \text{ moose.}$$

Confidence interval as a percentage of population estimate:

$$\begin{aligned} CI \text{ as } \pm \% \text{ of } \hat{T} &= 831 \pm \frac{(831 - 699)100}{831} \\ &= 831 \text{ moose } \pm 15.9\%. \end{aligned}$$

3.8.6 Data Summary for Population Estimation Surveys

Form 5 is used to list estimated values for strata and for the survey area (see Appendix 2 for blank form).

3.9 HEWLETT-PACKARD 97 PROGRAM: CALCULATING THE POPULATION ESTIMATE AND CONFIDENCE INTERVAL

3.9.1 Program Instructions

HP 97 program 1 in Appendix 1 estimates population size and confidence interval. Program instructions are in Table 10. The calculator display, which appears after a function key is depressed, indicates the step in the program and indicates the calculator is ready for data or an action appropriate for that step. For example, when the calculator display is "0.", you are at step 2 and need to press function key A.

3.9.2 Program Printout

The HP 97 printout format shown in Figure 19 uses data from the example in Section 3.8. The HP 97 prints only

numbers and asterisks. Three asterisks are normally printed at the right of each number; asterisks have been omitted in this example to conserve space. Symbols were added in this example to facilitate the identification of each number.

3.10 OPTIMALLY ALLOCATING SAMPLING EFFORT

Optimal allocation of sampling effort is the process of distributing sampling effort to produce the most precise population estimate, i.e., how to get the most precision for your dollar. The sampling effort is distributed among strata and between standard and intensive searches. Skip this section if your budget is infinite; however, study it carefully if funds are in short supply. Cochran (1977), Stuart (1984), and Scheaffer et al. (1979) present discussions on optimally allocating effort among strata. We use their methods of allocation among strata and a heuristic extension of their methods for allocating between standard and intensive search efforts.

Optimal allocation must be considered as soon as five SUs (or some other predetermined minimum greater than 5) have been searched in each stratum. We consider five SUs to be the minimum for estimating a variance; usually more than five SUs are surveyed in each stratum. Despite the need to optimally allocate early in the survey, its discussion follows the calculation of the population estimate because strata variances are used in the allocation process.

3.10.1 Basis for Optimal Allocation

Conventional procedure is to allocate search effort prior to the survey and base search effort on expected sample variance among strata; i.e., the greater the expected sample variance, the greater the proportion of SUs that must be searched. Also, the size of strata influences search effort with larger strata generally requiring more search effort. The survey is concluded when these SUs are searched. In lieu of specific variance estimates, relative density estimates are commonly used along with known strata sizes to allocate effort because density and variance are generally directly related. If unexpected variances occur, the allocation is, in the end, not optimal. In fact, variances commonly behave in unexpected ways because they are dependent on how well stratification partitioned the variance among all SUs.

To overcome the inaccuracy of estimating relative variances prior to sampling, we allocate sampling effort among strata on a daily basis during the survey and base the allocation on the observed sample variance estimates of the strata. In addition, by using observed sample variances, we allocate effort between standard and intensive searches.

We will first discuss allocating effort among strata. This will provide the basis for allocating effort among strata for standard searches and between standard and intensive searches.

Form 5. Moose population estimation survey--data summary.

Survey Area Fictitious Square Mountain
 Game Management Unit(s) 1 Subunit(s) A
 Date of Survey Nov 1983 Survey Supervisor Jones

DATA SUMMARY FOR STRATUM

STRATUM POPULATION ESTIMATE	Low stratum	Medium stratum	High stratum
A_1 = area (mi^2)	<u>276.0</u>	<u>240.0</u>	<u>156.0</u>
N_1 = total SUs	<u>23</u>	<u>20</u>	<u>13</u>
n_1 = no. SUs searched	<u>5</u>	<u>6</u>	<u>9</u>
\hat{d}_1 = obs. density	<u>0.166667</u>	<u>1.166667</u>	<u>2.750000</u>
\hat{T}_1 = est. no. moose (uncorrected)	<u>46.0</u>	<u>280.0</u>	<u>429.0</u>
$V(\hat{T}_1)$ = variance of \hat{T}_1	<u>124.200</u>	<u>1101.333</u>	<u>1393.889</u>

DATA SUMMARY FOR SURVEY AREA

SURVEY AREA INFORMATION	EXPANDED POPULATION ESTIMATE
Total area (mi^2) = <u>672.0</u>	SCF_c = sight. correction constant = <u>1.02</u>
Total No. SUs = <u>56</u>	\hat{T}_e = expand. pop. est. ($\hat{T}_o \times SCF_c$) = <u>815</u>
Total No. SUs searched = <u>20</u>	$V(\hat{T}_e)$ = variance of \hat{T}_e = <u>5002</u>
	v_e = degrees of freedom = <u>9</u>
OBSERVED POPULATION ESTIMATE	TOTAL POPULATION ESTIMATE
\hat{T}_o = obs. pop. est. (uncorrected) = <u>755.0</u>	\hat{T} = total pop. est. ($\hat{T}_e \times SCF_c$) = <u>832</u>
$V(\hat{T}_o)$ = variance obs. est. = <u>2619.42</u>	d = density = <u>1.24</u>
v_o = degrees of freedom = <u>14</u>	90% CI as % of \hat{T} = <u>15.9</u>
SCF_o = obs. sight. correction factor = <u>1.08</u>	CL_u = upper confidence limit = <u>964</u>
$V(SCF_o)$ = variance of SCF_o = <u>0.003400</u>	CL_l = lower confidence limit = <u>699</u>
n_o = no. SCF plots searched = <u>10</u>	SCF = sight. correct. factor ($SCF_o \times SCF_c$) = <u>1.10</u>
v_s = degrees freedom of SCF_o = <u>9</u>	

Table 10. Hewlett-Packard 97 program instructions for calculating a moose population estimate and confidence interval.

Step	Display value equals	Instruction	Printout value equals
1	0.00	LOAD both sides of card 1	
2	0.	PRESS A	
3	-111.	Choose either: (1) To enter SCF_o (observed sightability correction factor) data, go to step 4; or (2) To enter previously calculated SCF_o , $V(SCF_o)$, and v_s (degrees of freedom for SCF_o), go to step 8	
4	-111.	PRESS B	
5	0 or no. data sets entered	ENTER u_k (no. moose seen on intensive search) PRESS R/S [†]	u_k
6	u_k	ENTER v_k (no. moose seen on standard search) PRESS R/S [†] Repeat steps 5-6 until all SUs in stratum entered, then go to step 7	v_k
7	No. data sets entered	PRESS C Go to Step 12	n_o (no. intensive searches) SCF_o (observed sightability correction factor) $V(SCF_o)$ (variance) v_s (degrees freedom of SCF_o)
8	-111.	PRESS D	
9	-222.	ENTER SCF_o (observed sightability correction factor) PRESS R/S	SCF_o
10	SCF_o	ENTER $V(SCF_o)$ (variance of SCF_o) PRESS R/S	$V(SCF_o)$
11	$V(SCF_o)$	ENTER v_s (degrees freedom of SCF_o) PRESS R/S	v_s
12	-333.	Choose either: (1) To enter density data, go to step 13; or (2) To recalculate SCF_o go to step 4	
13	-333.	PRESS E	
14	-444.	ENTER A_i (total area for stratum) PRESS R/S ^{††}	A_i
15	A_i	ENTER N_i (total SUs for stratum) PRESS R/S ^{††}	N_i

Table 10. Continued.

Step	Display value equals	Instruction	Printout value equals
16	0.0 or no. data sets entered	ENTER y_j (no. moose counted in SU_j) PRESS R/S ^{†††}	y_j
17	y_i	ENTER x_j (area of SU_j) PRESS R/S ^{†††} Repeat steps 16-17 until all SUs in stratum are entered, then go to step 18	x_j
18	No. data sets entered	PRESS f, c	n_i (no. SUs surveyed in stratum) d_i (stratum density) \hat{T}_i (stratum population est.) $V(\hat{T}_i)$ (variance)
19		Choose either: (1) To enter more strata, go to step 14; or (2) If all strata are entered, go to step 20	
20	-444.	PRESS f, d	\hat{T}_o (observed population est.) $V(\hat{T}_o)$ (variance) ν_o (degrees freedom of \hat{T}_o)
21	-555.	LOAD both sides of card 2	
22	-555.	PRESS A	\hat{T}_e (expanded population est.) $V(\hat{T}_e)$ (variance) ν_e (degrees freedom of \hat{T}_e)
23	-666.	ENTER SCF_c (sightability correction factor constant) PRESS R/S	SCF_c \hat{T} (total population est.) $V(\hat{T})$ (variance)
24	-777.	Choose: (1) To enter new SCF_c , PRESS B, and return to step 23; or (2) To calculate 90% CI, PRESS D; or (3) To calculate 95% CI, PRESS E	% CI selected CI_l (lower confidence limit) CI_u (upper confidence limit) CI as \pm % of \hat{T} (i.e., $\hat{T} \pm \%$)
END OF PROGRAM		To rerun the program, return to step 1 and reload card 1	

[†] If an error is made entering u_k or v_k , finish entering both u_k and v_k until positioned at step 5 again, then PRESS f, b. ENTER initial u_k (whether erroneous or correct), PRESS R/S, and it will be printed. ENTER v_k , PRESS R/S, and it will be printed. Now you have removed the pair of values for sightability plot k that contained the error, and you are positioned again at step 5. Notice that the display value has decreased by 1 because the erroneous pair has been extracted. Proceed with step 5 and enter correct u_k or v_k .

^{††} If an error is made entering A_i or N_i , or if the entry of y_j 's and x_j 's is in a shambles, all information for current strata can be retracted by pressing E. All previous strata (strata for which f and c were pressed in step 18) will not be affected.

^{†††} If an error is made in entering y_j and x_j , finish entering both y_j and x_j until positioned at step 16, then PRESS f and b. ENTER erroneous y_j and x_j data set, PRESS R/S, and it will be printed. You will be positioned again at step 16. Notice that the display is 1 less in value than previously. Proceed with step 16 and enter correct y_j and x_j .

Printout	Symbol	Printout	Symbol	Printout	Symbol
1.08	SCF _o	10.0		9.	n _h
0.003400	V(SCF _o)	12.0		2.750000000	d _h
9.	ν _s	17.0		429.0	T̂ _h
		12.0		1393.889	V(T̂ _h)
		12.0			
276.0	A _l	12.0			
23.	N _l			755.0	T̂ _o
		6.	n _m	2619.42	V(T̂ _o)
2.0	y _j	1.166666667	d _m	14.	ν _o
12.0	x _j	280.0	T̂ _m		
2.0		1101.333	V(T̂ _m)		
12.0					
1.0				815.	T̂ _e
12.0		156.0	A _h	4984.	V(T̂ _e)
4.0		13.	N _h	9.	ν _e
12.0					
1.0		49.0	y _j	1.02	SCF _c
12.0		12.0	x _j	832.	T̂ _c
		57.0		5186.	V(T̂ _c)
5.	n _l	12.0			
0.166666667	d _l	41.0			
46.0	T̂ _l	12.0		90.	90% CI
124.200	V(T̂ _l)	23.0		700.	CL _l
		12.0		964.	CL _u
		32.0		15.9	CI as ± % T̂
240.0	A _m	12.0			
20.	N _m	6.0			
		12.0		95.	95% CI
9.0	y _j	35.0		669.	CL _l
12.0	x _j	12.0		995.	CL _u
14.0		35.0		19.6	CI as ± % T̂
12.0		12.0			
22.0		19.0			
12.0		12.0			

Figure 19. Example of the Hewlett-Packard 97 printout of the program for calculating the population estimate and associated confidence interval. The tape printout has been divided into three columns; complete column 1, proceed to column 2, and finally to 3.

3.10.2 Optimally Allocating Among Strata

The adjustment of sampling effort among strata is accomplished by using the sample variance of each stratum (s_{qi}^2 calculated in Section 3.7.1.3), stratum area (A_i), and mean area of SUs surveyed in a stratum to date (\bar{x}_i) to calculate a relative variation factor (RVF_i) for each stratum.

$$RVF_i = \frac{A_i}{\bar{x}_i} \sqrt{s_{qi}^2}$$

and

$$n_m^* \equiv \frac{RVF_m}{RVF_l} n_l^*$$

$$n_h^* \equiv \frac{RVF_h}{RVF_l} n_l^*$$

Optimal allocation of search effort is achieved by solving the approximate equations

$$n_h^* \equiv \frac{RVF_h}{RVF_m} n_m^*$$

where n_i^* is the optimal number of SUs to be searched in the i th stratum, $i = l, m, h$.

These equations are powerful tools that can be used to optimally allocate sampling effort as the survey progresses. To do this, allocate the remaining sampling effort so that the variance is minimized. When solving these equations, you must accept integer values for the n_i^* that satisfy the equations as nearly as possible because you only sample whole SUs. Also, realize that there are practical bounds for n_i^* . That is, n_i^* cannot be less than the number of SUs that have been sampled to date in the i th stratum, and it can be no larger than the total number of SUs in stratum i (N_i).

A numerical example to further explain the optimal allocation equations follows where $RVF_l = 26.73$, $RVF_m = 79.93$, and $RVF_h = 93.21$, and you have sampled five SUs in each stratum. Compute

$$n_m^* \cong \frac{RVF_m}{RVF_l} n_l^* = \frac{79.93}{26.73} n_l^* = 2.99 n_l^*$$

$$n_h^* \cong \frac{RVF_h}{RVF_l} n_l^* = \frac{93.21}{26.73} n_l^* = 3.49 n_l^*$$

and

$$n_h^* \cong \frac{RVF_h}{RVF_m} n_m^* = \frac{93.21}{79.93} n_m^* = 1.17 n_m^*.$$

The first two equations indicate that the medium- and high-density strata will require more of the remaining search effort than the low-density stratum. Because five SUs have already been flown in the low-density stratum, and it has the smallest variance as demonstrated by RVF_l , let $n_l^* = 5$ to determine optimal allocation in the medium- and high-density strata.

Compute

$$n_m^* \cong 2.99 n_l^*$$

$$n_m^* \cong 2.99 \times 5 \text{ SUs surveyed in the low-density stratum}$$

$$n_m^* = 15,$$

and

$$n_h^* \cong 3.49 n_l^*$$

$$n_h^* \cong 3.49 \times 5 \text{ SUs surveyed in the low-density stratum}$$

$$n_h^* = 17.$$

Given that five SUs have been flown in the low-density stratum, the most precise population estimate will be achieved if a total of 15 and 17 SUs are flown in the medium- and high-density strata, respectively.

Notice that the allocation equation,

$$n_h^* \cong \frac{RVF_h}{RVF_m} n_m^*$$

was not used to determine optimal allocation in this example. The three equations are redundant, and it is only necessary to use the first two equations when all three strata are being sampled. If the allocation equations indicate that sampling is sufficient for one stratum, then use the one equation appropriate for the other two strata.

In our example, the medium- and high-density strata need to be sampled much more intensively than the low-density, but suppose there is not enough money to do a total of 15 and 17 SUs in the medium- and high-density strata. Then use the third allocation equation and sample proportionally 1.17 high-density SUs to one medium-density SU until you have exhausted the money.

3.10.3 Optimally Allocating Effort Between Standard and Intensive Searches

The proportion of SUs searched intensively affects the variability in the expanded population estimate (\hat{T}_o). Therefore, the allocation of effort between standard and intensive searches can be optimized in a manner similar to allocation among strata (Section 3.10.2).

It is recommended that the allocation of effort between standard and intensive searches be monitored throughout the survey, but it is not advisable to update this allocation daily as is done with allocation among strata for estimates of observable moose. When the proportion of SUs to be intensively searched is changed in the middle of a survey, assumptions may be violated concerning the random selection of units to be intensively searched. Further, the equations offered below for determining the optimal number of SUs to intensively search are subject to the same sort of variation over the course of the survey as those equations presented in Section 3.10.2.

To determine the optimal number of SUs to intensively search, first follow the procedures in Section 3.10.2 to determine n_h^* , n_m^* , and n_l^* , where these values are the actual numbers of SUs you decide to search in each stratum. In addition, retain the RVF_s s from Section 3.10.2. Follow procedures in Section 3.6.5.3 to obtain the SCF_o and those in Section 3.7.2.1 to obtain the estimate of \hat{T}_o .

From these values, calculate

$$RVF_s^o = \hat{T}_o \sqrt{n_o \cdot V(SCF_o)},$$

$$RVF_h^o = SCF_o \cdot RVF_h,$$

$$RVF_m^o = SCF_o \cdot RVF_m,$$

and

$$RVF_l^o = SCF_o \cdot RVF_l.$$

It is generally less expensive to fly a 2-mi² intensive search than to fly a 12-mi² standard search. Therefore, in your determination of the optimal number of SUs to intensively search, consider the relative costs of the two types of searches. Relative costs are easily expressed in units of time. Determine for your survey

C_s = the number of minutes required to fly an intensive search of a 2-mi² sightability plot,

and

C_t = the number of minutes required to fly a standard search of a SU.

With the cost figures, calculate

$$n_h^o \cong \frac{RVF_s^o \sqrt{C_t}}{RVF_h^o \sqrt{C_s}} n_h^*,$$

$$n_m^o \cong \frac{RVF_s^o \sqrt{C_t}}{RVF_m^o \sqrt{C_s}} n_m^*,$$

and

$$n_l^o \cong \frac{RVF_s^o \sqrt{C_t}}{RVF_l^o \sqrt{C_s}} n_l^*.$$

The optimal number of SUs to intensively search, n^o , is the smaller of the three values, n_h^o , n_m^o , and n_l^o .

$$n^o = \text{minimum of } (n_h^o, n_m^o, n_l^o)$$

The value n_o can now be used as an index to determine if the division of effort is near the optimal allocation between standard and intensive searches, by calculating

$$\% \text{ difference} = 100 \frac{|n^o - n_o|}{n^o}$$

where n_o is the number of SUs you would intensively search at the current allocation of effort. If the difference is greater than 25%, you will probably see a cost savings by reallocating effort between standard and intensive searches. If the difference is less than 25%, consideration of a change in allocation should be postponed until more information is

collected. If it was advantageous to reallocate effort between standard and intensive searches, it may be necessary to recompute new values for n_i^* (Section 3.10.2) and n^o several times to arrive at a scheme that stays within your budget. Cheer up! This can be easily accomplished with the HP 97 program in Section 3.11. As with the allocation scheme among strata, the value of n^o will vary as more data are collected but will stabilize toward the end of the survey.

3.10.4 Example of Optimal Allocation

An example from the Square Mountain survey area will help illustrate optimal allocation. The goal is to produce the most precise expanded population estimate possible with 30.4 hours (1,825 min) of survey time. It takes 75 min of flight time to search a SU at 6 min/mi² and 30 min to perform an intensive search on a 2-mi² area.

At the outset, you anticipate, based on previous population estimates in this area, that intensive searches will be required in about 50% of the SUs chosen from the high and medium strata.

Day 1 of the survey results in data from three high-, two medium-, and two low-density strata (Table 11). No attempt is made to allocate search effort for day 2 because at least five SUs in each stratum have not been searched. The objective of the survey crews for day 2 is to survey at least two SUs from the high stratum, three from the medium, and three from the low.

After the second day of surveying, data exist for five SUs in each stratum (Table 11). From these data, the observable number of moose (\hat{T}_o) was estimated to be 846. You also intensively searched five 2-mi² sightability plots ($n_o = 5$), yielding $SCF_o = 1.053$ and $V(SCF_o) = 0.002862$. These values must be taken from the HP 97 program or hand calculations for population estimates (Section 3.6.5.3 and 3.9.2).

You used 1,275 min of the time and need to allocate the remaining 550 min. Calculate RVF_i for each stratum (Table 11), and the optimal allocation equations are

$$n_m^* \cong \frac{79.93}{26.73} n_l^* = 2.99 n_l^*,$$

$$n_h^* \cong \frac{93.21}{26.73} n_l^* = 3.49 n_l^*,$$

and

$$n_h^* \cong \frac{93.21}{79.93} n_m^* = 1.17 n_m^*.$$

The first two equations indicate that strata m and h will require more effort than stratum l. Using $n_l^* = 5$, we get $n_m^* = 15$, and $n_h^* = 17$. However, because the high stratum only has 13 total SUs, n_h^* can be no larger than 13. Therefore, use $n_h^* = 13$. Because five SUs have already been sampled in each strata and only 550 min remain to allocate, you cannot

Table 11. Data needed for calculating the optimum allocation of sampling effort for a population estimation survey in the fictitious Square Mountain survey area. Data are presented for the first two days of sampling.

Low stratum			Medium stratum			High stratum		
No. moose seen	SU ^a area (mi ²)	Stratum value	No. moose seen	SU area (mi ²)	Stratum value	No. moose seen	SU area (mi ²)	Stratum value
2	12.4		9	11.5		49	14.7	
2	10.9		14	11.2		57	15.0	
1	12.9		22	14.3		41	12.0	
4	13.1		10	11.0		23	10.7	
1	11.3		17	12.0		32	10.3	
Area of <i>i</i> th stratum (A _i) (mi ²)		277.7			240.2			158.9
Total SUs in <i>i</i> th stratum (N _i)		23			20			13
Mean SU area in <i>i</i> th stratum (\bar{x}_i)		12.12			12.00			12.54
<i>i</i> th stratum variance [V(\hat{T}_i)]		111.828			958.283			1069.250
Sample variance in <i>i</i> th stratum (s_{qi}^2)		1.3609			15.9448			54.1066
Relative variation factor [$(A_i/\bar{x}_i)\sqrt{s_{qi}^2}$]		26.73			79.93			93.21

^a SU equals sample unit.

expect to approach satisfaction of the first two equations. This situation periodically occurs. If the remaining effort is distributed within the high and medium strata, and if you wish to continue flying intensive searches in 50% of the high and medium SUs, then the 550 min could be proportioned into six standard and three intensive searches. The six standard and three intensive searches would require 450 and 90 min, respectively.

Now you must determine the best allocation of the six remaining SUs between the high and medium strata by computing

$$n_h^* + n_m^* = 16 \text{ total SUs to be flown,}$$

or

$$1.17 n_m^* + n_m^* \cong 16$$

where

$$n_h^* \cong 1.17 n_m^*.$$

Two of the remaining six SUs are subjectively allocated to the medium stratum, for a total allocation of seven medium SUs. Enter seven medium SUs in the allocation equation and compute

$$1.17 (7) + 7 \cong 16$$

$$8.19 + 7 \approx 16$$

$$15 \approx 16.$$

By surveying a total of seven SUs in the medium stratum, you have come very close to the optimal allocation, i.e., there is one additional SU which you decide to allocate to the high stratum. Eight medium SUs would mean nine highs should be sampled, which would exceed the budget of 16 total SUs in the medium and high strata. Therefore, the allocation becomes $n_t^* = 5$, $n_m^* = 7$, and $n_h^* = 9$. Maintaining your 50% rate of intensive searches in the high and medium stratum makes $n_o = 8$.

Now determine if the allocation of effort between standard and intensive searches is optimal. To check this allocation, calculate

$$RVF_s^o = 846 \sqrt{5 \times 0.002862} = 101.2,$$

$$RVF_h^o = 1.053 \times 93.21 = 98.15,$$

$$RVF_m^o = 84.17,$$

and

$$RVF_t^o = 28.15.$$

The cost figures (in units of survey time) are $C_s = 30$ min for intensive searches and $C_t = 75$ min for standard searches.

Calculate

$$n_h^o \approx \frac{101.20 \sqrt{75}}{98.15 \sqrt{30}} \times 9 = 14.7 \approx 15,$$

$$n_m^o \approx 13.3 \approx 13,$$

and

$$n_t^o \approx 28.4 \approx 28.$$

Thus,

$$n^o = \text{minimum of } (15, 13, 28) = 13$$

and

$$100 \frac{|n^o - n_o|}{n^o} = 100 \frac{|13 - 8|}{13} = 38.5\%.$$

The high percentage difference indicates that the current allocation deviates considerably from the optimum, hence consider adjusting it. Attempt to intensively survey 2-mi² plots in nearly 100% of the subsequently searched SUs to minimize the variance of the expanded population estimate.

As you cannot afford to do intensive searches in all of the high and medium SUs to be searched, try $n_t^* = 5$, $n_m^* = 7$, and $n_h^* = 8$. This allocation among strata will use 375 min of the remaining air time and leave enough to perform an intensive search on all five of the remaining SUs. Recalculating n_h^o will still yield $n^o = 13$. The best allocation of the remaining resources from current data is $n_t^* = 5$, $n_m^* = 7$, $n_h^* = 8$, and $n^o = 10$.

On the third day, you have poor weather but are able to perform a standard and intensive search on one SU in each of the high- and medium-density strata. Data for standard search effort appears in Table 12 with an estimate $\hat{T}_0 = 783$. Data for intensive searches with $n_o = 7$ yield $SCF_o = 1.042$ and $V(SCF_o) = 0.002703$.

The equations for allocation among strata give $n_t^* = 5$, $n_m^* = 6$, and $n_h^* = 9$. So shift the remaining effort to the high-density stratum and perform both types of search on each SU surveyed.

Again, checking the allocation between standard and intensive searches;

$$RVF_s^o = 783 \sqrt{7 \times 0.002703} = 107.70,$$

$$RVF_h^o = 1.042 \times 171.51 = 178.71,$$

$$RVF_m^o = 77.21,$$

$$RVF_t^o = 27.85,$$

and

$$n_h^o = 9,$$

$$n_m^o = 13,$$

$$n_t^o = 31.$$

So

$$n^o = \text{minimum of } (9, 13, 31) = 9.$$

Your planned effort of final $n^o = 10$ deviates little from $n^o = 9$. So, complete the survey on the fourth day by searching three SUs in the high stratum, with each SU getting a standard and intensive search.

This example demonstrates how the optimal allocation may vary during a survey. The equations never supply an absolute optimal allocation at any point in a survey, because the sample variance ($s_{q_i}^2$) is only an estimate of the overall

Table 12. Data needed for calculating the optimum allocation of sampling effort for a population estimation survey in the fictitious Square Mountain survey area. Data are presented for the first three days of sampling.

Low stratum			Medium stratum			High stratum		
No. moose seen	SU ^a area (mi ²)	Stratum value	No. moose seen	SU area (mi ²)	Stratum value	No. moose seen	SU area (mi ²)	Stratum value
2	12.4		9	11.5		49	14.7	
2	10.9		14	11.2		57	15.0	
1	12.9		22	14.3		41	12.0	
4	13.1		10	11.0		23	10.7	
1	11.3		17	12.0		32	10.3	
			12	11.6		6	9.9	
Area of <i>i</i> th stratum (A _i) (mi ²)		277.7			240.2			158.9
Total SUs in <i>i</i> th stratum (N _i)		23			20			13
Mean SU area in <i>i</i> th stratum (\bar{x}_i)		12.12			11.93			12.10
<i>i</i> th stratum variance [$V(\hat{T}_i)$]		111.828			640.618			2639.885
Sample variance in <i>i</i> th stratum (s_{qi}^2)		1.3609			13.5528			170.5707
Relative variation factor								
$[(A_i/\bar{x}_i)\sqrt{s_{qi}^2}]$		26.73			74.10			171.65

^aSU equals sample unit.

variation in a stratum. However, the equations do provide a best estimate of optimal allocation based on accumulated survey data and improve with the inclusion of each day's data.

3.10.5 Optimally Allocating Search Effort in Areas of Low Moose Density

Estimating a SCF₀ for a low-density moose population is not feasible (Section 3.6.5.5), hence you will not be flying intensive searches. Therefore, allocating search effort between standard and intensive searches is inapplicable. Under these circumstances, simply allocate effort among strata by solving for n_i (Section 3.10.2).

3.11 HEWLETT-PACKARD 97 PROGRAM: CALCULATING THE OPTIMAL ALLOCATION OF SAMPLING EFFORT

3.11.1 Program Instructions

HP 97 program 2 in Appendix 1 estimates the optimal sampling effort among strata and between standard and intensive searches. Program instructions are in Table 13. Using this program, either (1) base the allocation on budget and get the best allocation within budget limitations, or (2) disregard budget limitations and get the best allocation based on the variance of the population estimate. The calculator display, which appears after a function key is de-

Table 13. Hewlett-Packard 97 program instructions for calculating the optimal allocation of sampling effort.

Step	Display value equals	Instruction	Printout value equals
1	0.00	LOAD both sides of card 1	
2	0.	PRESS A	
3	-211.	Choose: (1) To enter low stratum data, PRESS B [†] ; or (2) To enter medium stratum data, PRESS C [†] ; or (3) To enter high stratum data, PRESS D [†]	
4	-222.	ENTER $V(\hat{T}_i)$ (variance of stratum population estimate) PRESS R/S ^{††}	$V(\hat{T}_i)$
5	$V(\hat{T}_i)$	ENTER N_i (total no. of SUs in stratum) PRESS R/S ^{††}	N_i
6	N_i	ENTER n_i (no. of SUs surveyed in stratum) PRESS R/S ^{††}	n_i RVF _i (relative variation factor)
7	-211.	Choose either: (1) To enter more strata, go to step 3; or (2) If all strata are entered, go to step 8.	
8	-211.	PRESS E	
9	-233.	ENTER $V(SCF_o)$ (variance of observed sightability correction factor) PRESS R/S ^{†††}	$V(SCF_o)$
10	$V(SCF_o)$	ENTER n_o (no. of intensive searches flown) PRESS R/S ^{†††}	n_o
11	n_o	ENTER \hat{T}_o (observed population est.) PRESS R/S ^{†††}	\hat{T}_o
12	\hat{T}_o	ENTER SCF_o (observed sightability correction factor) PRESS R/S ^{†††}	SCF_o RVF _s ^o (relative variation factor between standard and intensive searches) RVF _t ^o RVF _m ^o RVF _h ^o
13	0.0	ENTER C_t (no. of min. or dollars for standard search) PRESS R/S	C_t
14	C_t	ENTER C_s (no. of min. or dollars for intensive search) PRESS R/S	C_s

Table 13. Continued.

Step	Display value equals	Instruction	Printout value equals
15	-244.	LOAD both sides of card 2 PRESS A	
16	-255.	Choose either: (1) To calculate optimum allocation based on budget, go to step 17; or (2) To calculate optimum allocation by entering hypothetical n_i and disregarding budget, go to step 19.	
17	-255.	PRESS E	
18	-277.	ENTER maximum budget (must be same units as C_t and C_s) ⁺⁺⁺⁺ PRESS R/S (several min. may be required for computation) END PROGRAM or go to step 16	Max. budget n_t^* (optimum no. of standard searches in low stratum) n_m^* n_h^* n^o (optimum no. of intensive searches) Total cost with this allocation ⁺⁺⁺⁺
19	-255.	Choose: (1) To use low stratum as base, PRESS B; or (2) To use medium stratum as base, PRESS C; or (3) To use high stratum as base, PRESS D.	
20	-266.	ENTER a hypothetical n_i base (This n_i may be fractional, less than the current n_i , or greater than N_i . Program will ensure that final allocation has reasonable integer values.) PRESS R/S	n_i base (hypothetical no. SUs to survey in stratum) n^* (optimum allocation in low) n_m^* n_h^* n^o (optimal no. of intensive searches) Total cost
21	-255.	Choose: (1) To compute an allocation with a different n_i base, go to step 19; or (2) To compute an allocation based on maximum budget, go to step 17; or (3) END PROGRAM	

Table 13. Continued.

[†] The HP 97 program must receive data for three strata in step 3. If your survey area has only one or two strata, you must enter the following data for the nonexistent stratum:

- (1) For $V(\hat{T}_i)$ in step 4, ENTER 0.0001
- (2) For N_i in step 5, ENTER 1
- (3) For n_i in step 6, ENTER 1

The nonexistent stratum will be allocated one SU, and the program will also charge the cost of that SU to your maximum budget. Therefore, you can afford one more SU than indicated by the program.

^{††} If an error is made entering data for a particular stratum, press the corresponding function key in step 3 and reenter all data for that stratum.

^{†††} If an error is made entering data in steps 9 to 12, return to step 2 and begin again.

^{††††} During the first few days of a population estimate survey, do not enter the maximum value of your budget in this step. Instead, enter the value of your anticipated expenditures for the next 2 to 3 days. Because stratum variances and allocations change as the survey progresses, entering your maximum budget early in the survey may cause you to calculate and attempt an allocation that will substantially differ from what you will calculate with more data.

^{†††††} The program may produce an optimal allocation that does not use quite all of the available budget. You may have enough money left over to search one or two more SUs or fly an intensive search. If the total cost printed in step 20 does not use all of your budget, use the following steps to optimally allocate the remainder:

1. PRESS DSP
2. PRESS 4
3. PRESS RCL
4. PRESS 4

The calculator will now display the noninteger value of n_i^* in your final allocation. Write this number down.

5. Go to step 19 and PRESS B
6. Go to step 20. By increasing the size of noninteger n_i^* in small increments (< 0.01) and substituting it for n_i base in step 20, you can allocate the remainder of your budget. Continue pressing B and entering slightly larger values for n_i base until total cost equals or exceeds your budget.
7. The following printout results:

n_i base (hypothetical no. SUs in stratum)
 n_i^* (optimal allocation in low stratum)
 n_m^* (optimal allocation in medium stratum)
 n_h^* (optimal allocation in high stratum)
 n^0 (optimal no. intensive searches)

Total cost (minutes or dollars) of this allocation

8. Choose either:
 - (1) To repeat the procedure, PRESS B, C, or D; or
 - (2) To continue allocation program at step 16, PRESS E

Optimum allocation at end of day 2		Optimum allocation at end of day 3		Attempt to allocate unused portion of budget	
Printout	Symbol	Printout	Symbol	Printout	Symbol
111.828	$V(\hat{T}_l)$	111.828	$V(\hat{T}_l)$	1.4810	n_i base
23.	N_l	23.	N_l		
5.	n_l	5.	n_l	5.	n_l^*
26.72932223	RVF_l	26.72932223	RVF_l	6.	n_m^*
				10.	n_h^*
				9.	n_o^*
958.283	$V(\hat{T}_m)$	640.618	$V(\hat{T}_m)$		
20.	N_m	20.	N_m	1845.	Total Cost
5.	n_m	6.	n_m		
79.92842632	RVF_m	74.10135914	RVF_m	1.4801	n_i base
1069.250	$V(\hat{T}_h)$	2639.885	$V(\hat{T}_h)$	5.	n_l^*
13.	N_h	13.	N_h	6.	n_m^*
5.	n_h	6.	n_h	9.	n_h^*
93.20759759	RVF_h	171.5105286	RVF_h	9.	n_o^*
				1770.	Total Cost
0.002862	$V(SCF_o)$	0.002703	$V(SCF_o)$		
5.	n_o	7.	n_o	1.4805	n_i base
846.	\hat{T}_o	783.	\hat{T}_o	5.	n_l^*
1.053000	SCF_o	1.042000	SCF_o	6.	n_m^*
				9.	n_h^*
101.2022527	RVF_s^o	107.7044891	RVF_s^o	9.	n_o^*
28.14597631	RVF_l^o	27.85195376	RVF_l^o	1770.	Total Cost
84.16463291	RVF_m^o	77.21361622	RVF_m^o		
98.14760026	RVF_h^o	178.7139708	RVF_h^o		
75.0	C_t	75.0	C_t		
30.0	C_s	30.0	C_s		
1825.0	Max. Budget	1825.0	Max. Budget		
5.	n_l^*	5.	n_l^*		
7.	n_m^*	6.	n_m^*		
8.	n_h^*	9.	n_h^*		
10.	n_o^*	9.	n_o^*		
1800.	Total Cost	1770.	Total Cost		

Figure 20. Example of the Hewlett-Packard 97 printout of the program for calculating the optimal allocation of sampling effort during population estimation surveys. The tape printout has been divided into three columns; complete column 1, proceed to column 2, and finally to 3.

pressed, indicates the step in the program and indicates the calculator is ready for data or an action appropriate for that step. For example, when the calculator display is “-211.”, you are positioned at step 3 and need to press the function key corresponding to the stratum data being entered. The calculator printout does not list each step in the same order as the optimal allocation example in Section 3.10.4.

3.11.2 Program Printout

The HP 97 printout format shown in Figure 20 uses data from the example in Section 3.10.4. The HP 97 prints only numbers and asterisks. Three asterisks are normally printed at the right of each number; asterisks have been omitted in this example. Symbols were added in this example to facilitate the identification of each number.

3.12 SUMMING POPULATION ESTIMATES FROM ADJACENT AREAS

Two or more population estimates from adjacent areas can be summed to estimate numbers of moose in the entire area. The summed population estimate (\hat{T}_s) is calculated as

$$\hat{T}_s = \hat{T}_1 + \hat{T}_2 + \dots + \hat{T}_n$$

where \hat{T}_i is one of the estimates, $i = 1 \dots n$ estimates.

The sampling variance of \hat{T}_s is

$$V(\hat{T}_s) = V(\hat{T}_1) + V(\hat{T}_2) + \dots + V(\hat{T}_n).$$

The degrees of freedom associated with the summed estimate (Satterthwaite 1946) is

$$\nu_{es} = \frac{[V(\hat{T}_1) + V(\hat{T}_2) + \dots + V(\hat{T}_n)]^2}{\frac{V(\hat{T}_1)^2}{\nu_{e1}} + \frac{V(\hat{T}_2)^2}{\nu_{e2}} + \dots + \frac{V(\hat{T}_n)^2}{\nu_{en}}}$$

The confidence interval for the summed estimate is calculated as in Section 3.7.5.2, except \hat{T}_s , $V(\hat{T}_s)$, and ν_{es} are substituted for \hat{T} , $V(\hat{T})$, and ν_e .

3.13 SURVEY COSTS

Survey expenses can be divided into the following categories: (1) materials, (2) stratification, (3) standard SU searches, (4) intensive searches for estimating sightability, (5) ferry time, and (6) food and lodging. The following cost estimation procedures provide crude estimates, at best.

3.13.1 Materials

The cost of materials such as topographic maps, acetate, and other supplies is a very small proportion of the total expenses. Buy enough supplies to keep the survey progressing efficiently. The price can be high if planes are grounded because of depleted supplies.

3.13.2 Stratification

Stratification costs can be approximated as follows: size of survey area (mi^2) \div 150 mi^2 stratified per hour \times hourly air charter cost. In addition, you will have to include estimated cost of ferry time (Section 3.13.5). Use Form 6 to monitor air charter expenses during a survey (see Appendix 2 for blank form).

3.13.3 Sample Unit Searches

Costs per SU searched include the flight time to locate the SU boundaries and flight time to survey the SU at 4 to 6 min/mi^2 . Approximately 3 to 20 min are required to locate SU boundaries, depending on the terrain. Search time is dependent on the number of moose in the SU. Approx-

mately 1.0 hours is required to search a SU if few groups of moose are observed, whereas 1.2 hours or more are required if 10 to 15 groups are observed.

Cost of searching SUs is estimated as follows: approximate number of SUs to be searched \times 1.3 hours of air charter per SU \times hourly air charter cost.

3.13.4 Intensive Searches of Sightability Plots

Sightability plot boundaries can generally be located in less than 5 min because you are already familiar with the entire SU. Flying the intensive search takes approximately 0.5 hours. Estimate the cost of the SCF₀ as follows: 0.5 hours flight time \times number of intensive searches expected \times hourly air charter cost.

3.13.5 Ferry Time

Ferry time is the time required to fly from the base of operations to the center of the survey area and return, plus the time required to fly between SUs during the day. Ferry time increases with the size of the survey area and its distance from the base. Ferry time to and from the survey area is estimated as follows: round trip flight time in hours to center of survey area \times number of round trips per day per aircraft \times number of aircraft used per day \times hourly air charter cost \times number of days required to complete the survey + a safety margin equaling the cost of one extra round trip per aircraft during the survey. Ferry time between SUs is estimated as follows: (number of SUs a plane will search per day - 1) \times 0.25 hours \times number of aircraft flying per day \times number of days required to complete the survey \times hourly air charter cost.

Ferry time between the survey area and the base may be reduced by placing fuel caches in the survey area, thus allowing aircraft to remain in the survey area all day. However, aircraft equipped with long-range fuel tanks save more time and dollars. Ferry time between SUs can be minimized by assigning a tight cluster of SUs to each aircraft.

3.13.6 Food and Lodging

Cost of food and lodging is quite variable. If personnel return home each day, these expenses are zero, but costs can exceed \$2,000 if people are lodged in commercial facilities. Form 7 will help monitor food and lodging expenses during a survey (see Appendix 2 for a blank form).

3.13.7 Survey Costs in Small Areas

Surveying small areas costs proportionately more than large areas. For example, to produce population estimates of comparable precision, 20 to 25% of a large survey area may have to be sampled versus 50 to 90% of a small area (300 to 700 mi^2). In small areas, it may be necessary to sample most, if not all, SUs in a stratum, particularly high- and medium-density strata. We recommend survey areas smaller than 300 mi^2 be surveyed in their entirety, saving the expense of stratification.

Game Management Unit(s) 1 Subunit(s) A

Air taxi Hourly rate	Date					
	11/4/83 No. hrs Cost	11/5/83 No. hrs Cost	/ / No. hrs Cost	/ / No. hrs Cost	/ / No. hrs Cost	/ / No. hrs Cost
Far North Air	6.2	6.3				
C-185 @ \$175/hr	\$1085	\$1103				
Alaska Air Service		3.9				
PA-18 @ \$120/hr		\$488				
Daily costs	\$1085	\$2696				
Cumulative daily costs	\$1085	\$3781				

Form 7. Daily food and lodging expenses during a moose population estimation survey.

Survey Area Fictitious Square MountainGame Management Unit(s) 1 Subunit(s) A

Person	Date									
	11/4/83	11/5/83	/ /	/ /	/ /	/ /	/ /	/ /	/ /	/ /
	Room Board	Room Board	Room Board	Room Board	Room Board	Room Board	Room Board	Room Board	Room Board	Room Board
Gasaway	\$ 20 \$ 25	\$ 20 \$ 25	—	—	—	—	—	—	—	—
DuBois	\$ 20 \$ 25	\$ 20 \$ 25	—	—	—	—	—	—	—	—
Harbo	\$ 20 \$ 25	\$ 20 \$ 25	—	—	—	—	—	—	—	—
Red	\$ 20 \$ 25	\$ 20 \$ 25	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—
Daily Costs	\$ 180	\$ 180								
Cumulative Daily costs	\$ 180	\$ 360								

3.14 MATERIALS LIST FOR POPULATION ESTIMATION SURVEYS

The following materials are required for population surveys. Numbers in parentheses indicate minimum quantity needed; the quantity of other items required will vary with the number of pilot-observer teams used in the survey.

Topographic maps (7 sets of 1:63,360 scale and 4 sets of 1:250,000 scale)

Number 2 lead pencils

Colored pencils

Grease pencils (3 colors, 3 each)

Large erasers (4)

Large scissors (3 pair)

Large felt-tip markers (2)

Transparent colored markers (3)

Clear tape (8 rolls)

Masking tape (1 roll)

Heavy gauge acetate at least 40 in wide (enough to cover a 1:63,360 scale map of the entire survey area)

Expandable file folders for storage of maps and data sheets (6)

Clipboards

Survey data sheets

Watch

Intercoms and headsets

Spare batteries for intercoms

Survival gear

Foam pads to sit on in plane

Air sickness pills and bags

Sunglasses

Yellow glasses for overcast days

Ear plugs

Hewlett-Packard 97 (HP 97) calculator and 2 sets of programs

Extra batteries and paper for HP 97

Instruction manual for HP 97

Polar compensating planimeter (1)

Tracing paper to be used with the planimeter

Pad of writing paper

Spare battery-powered calculator that can perform the required calculations in case the programmed HP 97 malfunctions

3-ring notebook to store all forms, calculations, and notes

4. DETECTING CHANGES IN POPULATION SIZE AND ESTIMATING RATES OF CHANGE

4.1 INTRODUCTION

Detecting changes in numbers and estimating the rates of growth or decline are vital for evaluating your management programs, formulating hunting regulations, or evaluating factors that control moose populations (Gasaway and Du-Bois 1987). However, population estimates are, by definition, not exact measures of population size, so we rely on statistical procedures to calculate the probability that a change occurred and the probable rate of that change. Our ability to identify a change in population size is directly related to the precision of the estimates; the greater the precision, the smaller the change that can be detected.

4.2 DETECTING CHANGES IN POPULATION SIZE

4.2.1 Detecting a Change in Population Size from Two Independent Estimates

4.2.1.1 Introduction to Student's *t*-test

Student's *t*-test is used to determine the probability of two populations differing in size. Before proceeding with a statistical test, you should have in mind the three values, α , β , and CD, which are defined as follows:

- α —The acceptable probability of error (from a practical point of view) if you were to conclude that a change in numbers had occurred when in fact it had not changed, i.e., a Type I error.
- β —The acceptable probability of error (from a practical point of view) if you were to conclude that no change in numbers larger than CD had occurred when in fact it had changed, i.e., a Type II error.
- CD—The consequential difference of interest, i.e., the minimum change in population size that would probably cause some change in management strategy.

A change in population size smaller than CD might be statistically significant, but the knowledge that the difference is statistically significant would be of little practical value. The CD needs to be established before values for α and β are considered.

Green (1979) explains α and β in the following way. The test of a null hypothesis (H_0) results in accepting or rejecting the hypothesis, based on some estimated risk of being wrong. The probability of rejecting H_0 when it is true (Type I error), i.e., concluding change occurred when it did not, is usually of most concern. The largest acceptable risk of committing a Type I error is commonly set at $\alpha = 0.05$; however, the 5% level of significance is only a convention. If H_0 (e.g., the population size did not change) is tested at α

$= 0.05$, then a significant result means that, based on the evidence, there is less than a 1-in-20 chance that a significant change did not occur, and that is an acceptably low risk of being wrong. Testing at $\alpha = 0.01$ means the risk of a Type I error must be 1-in-100 or lower to be acceptable.

However, for any given sampling and statistical analysis design, lowering the Type I error level (α) will increase the Type II error level (β), which is the probability of concluding that H_0 is true when in fact it is not. Here you falsely conclude that no change occurred. There is always a tradeoff; you will have to determine the consequences of making each type of error. For example, if you try to increase a moose population by decreasing the rate of harvest for 3 years, you want to be sure the strategy was effective before concluding so. Therefore, specify an α to guard against a Type I error. If the harvest strategy was effective, you want to have a good chance of detecting it; therefore, you must guard against making a Type II error (i.e., not detecting a change when it occurred). If a significant change is not detected, then you conclude the new harvest strategy had no effect and further reduction in harvest may be required. A Type II error results in unnecessary loss of hunting opportunity for moose hunters, whereas a Type I error maintains a harvest strategy that is not resulting in real population growth. Both errors have management implications, so consider both when testing hypotheses. The only way to reduce one error level without increasing the other is to improve the design. For example, increasing the number of samples would reduce either Type I or Type II errors or both.

Student's *t*-statistic is used to make two types of tests that detect if changes in population size are statistically significant. Use two-tailed tests when there is no preconceived idea whether the population increased or decreased. Two-tailed tests detect a change, if it occurred, in either direction. The critical values for two-tailed tests are presented in Table 8. In contrast, one-tailed tests detect change in a specific direction. For example, you may want to detect an increase in moose numbers following predator reduction. The critical values for one-tailed tests are presented in Table 14. Differences in application of one- and two-tailed tests are apparent in the statement of their associated alternative test hypothesis. Zar (1984:126) discusses using the *t*-test to test for differences in population means, which we will extend to testing for differences in population size.

When testing for differences in two population estimates, both estimates must be corrected for sightability bias to ensure differential sightability between years does not negate test results. For example, two estimates may be equal before correcting for sightability but may differ greatly after correction (Table 15). Conversely, two estimates could be different before correction but similar after correction (Table 16).

Table 14. Critical values of Student's *t*-distribution for one-tailed tests (α) and Type II error (β).

Degrees of freedom (<i>v</i>)	α and β probability							
	.40	.30	.20	.15	.10	.05	.025	.01
1	.325 ^b	.727	1.376	1.963	3.078	6.314	12.706	31.821
2	.289	.617	1.061	1.386	1.886	2.920	4.303	6.965
3	.277	.584	.978	1.250	1.638	2.353	3.182	4.541
4	.271	.569	.941	1.190	1.533	2.132	2.776	3.747
5	.267	.559	.920	1.156	1.476	2.015	2.571	3.365
6	.265	.553	.906	1.134	1.440	1.943	2.447	3.143
7	.263	.549	.896	1.119	1.415	1.895	2.365	2.998
8	.262	.546	.889	1.108	1.397	1.860	2.306	2.896
9	.261	.543	.883	1.100	1.383	1.833	2.262	2.821
10	.260	.542	.879	1.093	1.372	1.812	2.228	2.764
11	.260	.540	.876	1.088	1.363	1.796	2.201	2.718
12	.259	.539	.873	1.083	1.356	1.782	2.179	2.681
13	.259	.538	.870	1.079	1.350	1.771	2.160	2.650
14	.258	.537	.868	1.076	1.345	1.761	2.145	2.624
15	.258	.536	.866	1.074	1.341	1.753	2.131	2.602
16	.258	.535	.865	1.071	1.337	1.746	2.120	2.583
17	.257	.534	.863	1.069	1.333	1.740	2.110	2.567
18	.257	.534	.862	1.067	1.330	1.734	2.101	2.552
19	.257	.533	.861	1.066	1.328	1.729	2.093	2.539
20	.257	.533	.860	1.064	1.325	1.725	2.086	2.528
21	.257	.532	.859	1.063	1.323	1.721	2.080	2.518
22	.256	.532	.858	1.061	1.321	1.717	2.074	2.508
23	.256	.532	.858	1.060	1.319	1.714	2.069	2.500
24	.256	.531	.857	1.059	1.318	1.711	2.064	2.492
25	.256	.531	.856	1.058	1.316	1.708	2.060	2.485
26	.256	.531	.856	1.058	1.315	1.706	2.056	2.479
27	.256	.531	.855	1.057	1.314	1.703	2.052	2.473
28	.256	.530	.855	1.056	1.313	1.701	2.048	2.467
29	.256	.530	.854	1.055	1.311	1.699	2.045	2.462
30	.256	.530	.854	1.055	1.310	1.697	2.042	2.457
40	.255	.529	.851	1.050	1.303	1.684	2.021	2.423
60	.254	.527	.848	1.046	1.296	1.671	2.000	2.390
120	.254	.526	.845	1.041	1.289	1.658	1.980	2.358
∞	.253	.524	.842	1.036	1.282	1.645	1.960	2.326

^a Discussion of Type II (β) error is found in section 4.2.1.1.

^b These values were extracted from Appendix Table II of Simpson et al. (1960).

4.2.1.2 Two-tailed *t*-test

Hypotheses for a two-tailed test are

H_0 : The population size has not changed, i.e., $T_1 = T_2$

H_a : The population size has increased or decreased, i.e., $T_1 \neq T_2$

where T_1 is the population size at time 1 and T_2 is the population size at time 2.

The *t*-statistic, t' , is the test statistic and is calculated as

$$t' = \frac{\hat{T}_2 - \hat{T}_1}{\sqrt{V(\hat{T}_1) + V(\hat{T}_2)}}$$

where \hat{T}_1 estimates T_1 , \hat{T}_2 estimates T_2 , and $V(\hat{T}_i)$ is the

variance of the estimate \hat{T}_i , $i = 1, 2$.

An estimate of the number of degrees of freedom (ν_t) associated with the test statistic, t' , is calculated as

$$\nu_t = \frac{[V(\hat{T}_2) + V(\hat{T}_1)]^2}{\frac{V(\hat{T}_2)^2}{\nu_{e2}} + \frac{V(\hat{T}_1)^2}{\nu_{e1}}}$$

where ν_{ei} represents the degrees of freedom of the estimate \hat{T}_i , $i = 1, 2$. The value ν_t may be rounded to the nearest integer.

To make the test, consult the table of critical *t*-values for two-tailed tests (Table 8) and find t_{α, ν_t} for a two-tailed test. Reject H_0 in favor of H_a .

Table 15. The effect of variable sightability on estimated total moose.

Year	Estimated no. of observable moose	x	Sightability correction factor	=	Total population estimate
1	1,000		1.10		1,100
2	1,000		1.25		1,250

$$t' \geq t_{\alpha, \nu_t}$$

or if

$$t' \leq -t_{\alpha, \nu_t}$$

If you accept H_a and conclude (with probability of error α) that population size has changed, then compare the estimated change, $\hat{\Delta}_T = \hat{T}_2 - \hat{T}_1$, with the CD. Determine if the statistically significant $\hat{\Delta}_T$ is of practical significance and address what this means, in biological terms, for the population.

If you do not reject H_0 , you must determine if H_0 can actually be accepted with a tolerable probability of error, β . The following procedure allows you to qualify a conclusion of no change in population size by establishing a confidence level associated with that conclusion. Calculate

$$t^o = \frac{CD - \sqrt{V(\hat{T}_2) + V(\hat{T}_1)} \times t_{\alpha, \nu_t}}{\sqrt{V(\hat{T}_2) + V(\hat{T}_1)}}$$

Then, go to the table of t -values for Type II error (β) (Table 14) and find the row of t -values for the proper ν_t . Move across the row until t^o fits between two t -values, or $t = t^o$ is found. Now visually interpolate to find the probability (β_o) of t^o , using the probability in Table 14 for β_o .

The value, $1 - \beta_o$, is the probability that a difference of size CD could have been detected, if that difference existed. This is called the power of the test. If β_o is equal to or less than β , then accept H_0 with the predetermined acceptable error probability and conclude that if any change in population size occurred, it was smaller than CD and not of practical importance. If β_o is greater than β , then you are left without a satisfactory conclusion. A precise statement of the test results would be: you were unable to detect a significant change in population size at the α level of error probability. The probability of detecting a change in population size of CD was $1 - \beta_o$. If you conclude that no change in size as large as CD occurred, you do so with β probability of error.

Comment: Critical t -values for Type II error (β) and figuring the power of a test are always taken from Table 14, whether the test is one- or two-tailed.

Table 16. The effect of variable sightability on estimated total moose.

Year	Estimated no. of observable moose	x	Sightability correction factor	=	Total population estimate
1	909		1.10		1,000
2	800		1.25		1,000

4.2.1.3 Example: a two-tailed t -test

Moose population estimates were made during 1975 and 1980 in the Square Mountain survey area. The following data were collected:

$$\begin{aligned} \hat{T}_1 &= 755 \text{ moose} & \hat{T}_2 &= 830 \text{ moose} \\ V(\hat{T}_1) &= 2619 & V(\hat{T}_2) &= 2163 \\ \nu_{e1} &= 14 & \nu_{e2} &= 14. \end{aligned}$$

You decide to use a two-tailed Student's t -test to determine if there has been a significant change in the size of the Square Mountain moose herd during the 5-year period. Hypotheses for the test are

H_0 : The population size has not changed, i.e., $\hat{T}_1 = \hat{T}_2$, and

H_a : The population size has increased or decreased, i.e., $\hat{T}_1 \neq \hat{T}_2$.

The following criteria are established for the t -test:

$$\begin{aligned} CD &= 30\% \text{ of } \hat{T}_1 = 227 \\ \alpha &= 0.10 \\ \beta &= 0.20 \end{aligned}$$

Student's t -statistic is

$$t' = \frac{830 - 755}{\sqrt{2,163 + 2,619}} = 1.085.$$

Refer to Section 4.2.1.2 for formulae corresponding to calculations in this Section. Degrees of freedom for t' are

$$\nu_t = \frac{(2163 + 2619)^2}{\frac{2163^2}{14} + \frac{2619^2}{14}} = 27.7 \approx 28.$$

Now consult Table 8 and locate $t_{0.10, 28}$, which equals 1.701. You find t' less than t , i.e., 1.085 less than 1.701. Therefore, you fail to reject H_0 : $\hat{T}_1 = \hat{T}_2$. Because H_0 was not rejected, it is necessary to determine if H_0 can be accepted with a tolerable probability of committing a Type II error (β). Calculate

$$t^o = \frac{227 - \sqrt{2163 + 2619} (1.701)}{\sqrt{2163 + 2619}} = 1.579.$$

Turn to Table 14 and find that for $v_t = 28$, t_α is between 1.313 and 1.701. By visually interpolating, you estimate $\beta_0 \approx 0.07$. The value of $1 - \beta_0$ or $1 - 0.07$ equals 0.93, which is the probability of detecting a difference of size CD, if it existed. This is the power of the test. Because β_0 is less than β (i.e., $0.07 < 0.20$), you accept H_0 with a 0.20 probability of error and conclude that if any change occurred, it was smaller than CD (i.e., 227) and not of practical importance.

4.2.1.4 One-tailed t -test

Hypotheses for a one-tailed test to test for an increase in population size are

H_0 : The population size has not increased, i.e., T_1 equal to or greater than T_2 , and

H_a : The population size has increased, i.e., T_1 less than T_2 .

The test statistic is calculated as

$$t' = \frac{\hat{T}_2 - \hat{T}_1}{\sqrt{V(\hat{T}_2) + V(\hat{T}_1)}}$$

Degrees of freedom (v_t) is calculated as in the two-tailed t -test (Section 4.2.1.2, also see Section 4.2.1.2 for definition of notations, e.g., $V(\hat{T}_2)$ or v_t).

To make the test, consult the t -table for one-tailed tests (Table 14) and find t_{α, v_t} . Reject H_0 in favor of H_a if t' equal to or greater than t_{α, v_t} .

If you accept H_a and conclude (with probability of error α) that a statistically significant increase in population size occurred, compare the estimated increase, $\hat{D}_T = \hat{T}_1 - \hat{T}_2$, with CD and establish whether this difference is of practical importance.

If you do not reject H_0 , you can find the power of the test by calculating

$$t^o = \frac{CD - \sqrt{V(\hat{T}_2) + V(\hat{T}_1)} \times t_{\alpha, v_t}}{\sqrt{V(\hat{T}_2) + V(\hat{T}_1)}}$$

Then, by interpolating from the table of t -values (Table 14), as described for the two-tailed test, find the probability (β_0) associated with t^o , using probabilities in Table 14 for a one-tailed test. The value $(1 - \beta_0)$ is the probability that an increase of size CD could have been detected, if an increase of this size had occurred. If β_0 is equal to or less than β , conclude (with probability of error β) that no increase as large as CD occurred. If β_0 is greater than β , then the results are inconclusive with respect to your established criteria of CD, α , and β .

Hypotheses for a one-tailed test to test for a decrease in population size are

H_0 : T_1 equal to or less than T_2 , and

H_a : T_1 greater than T_2 .

Procedures are the same as testing for an increase in population size if you replace $(\hat{T}_2 - \hat{T}_1)$ with $(\hat{T}_1 - \hat{T}_2)$ in the calculations of t' , \hat{D}_T , and t^o .

4.2.1.5 Combining two independent estimates from a single population

A procedure is available that allows two independent estimates from a single population to be combined to obtain a more precise overall estimate. The procedure weights each independent estimate by the inverse of the sampling variance of that estimate so that the combined estimate has the smallest variance possible of any weighted unbiased combination of the two independent estimates. The application of this method is limited by the critical assumption that the two independent estimates estimate the same population parameter. This procedure accounts only for sampling variation around the two independent estimates and does not address variation in actual population size over time. Therefore, you must be satisfied that population size did not vary when the two estimates were made. To test the validity of this assumption, decide, based on the dynamics of the study population, if variation in actual population size between estimates was negligible. If satisfied that the expected temporal variation was negligible, then test the independent estimates quantitatively by determining a CD (based on what you consider negligible), an α , and a β . Then compute a two-tailed t -test (Section 4.2.1.2). If, at an acceptable level of β , there is no difference between the two estimates, combine them to form an improved estimator. The improved estimator \hat{T}^* is calculated

$$\hat{T}^* = \frac{\frac{\hat{T}_1}{V(\hat{T}_1)} + \frac{\hat{T}_2}{V(\hat{T}_2)}}{\frac{1}{V(\hat{T}_1)} + \frac{1}{V(\hat{T}_2)}}$$

or

$$\hat{T}^* = \frac{\hat{T}_1 \cdot V(\hat{T}_2) + \hat{T}_2 \cdot V(\hat{T}_1)}{V(\hat{T}_1) + V(\hat{T}_2)}$$

and its variance, $V(\hat{T}^*)$, is calculated

$$V(\hat{T}^*) = \frac{V(\hat{T}_1)V(\hat{T}_2)}{V(\hat{T}_1) + V(\hat{T}_2)}$$

where \hat{T}_i is one of the independent estimates, $i = 1, 2$; and $V(\hat{T}_i)$ is the variance of estimate \hat{T}_i .

To construct a CI around the estimator \hat{T}^* , estimate the degrees of freedom by

$$\nu^* = \frac{\nu_{e1}\nu_{e2}[V(\hat{T}_1) + V(\hat{T}_2)]^2}{\nu_{e2}V(\hat{T}_2)^2 + \nu_{e1}V(\hat{T}_1)^2}$$

where v_{ei} is the number of degrees of freedom associated with the estimate \hat{T}_i , $i = 1, 2$, and select the appropriate t -value from Table 8.

The CI is calculated as described in Section 3.7.5.

4.2.2 Planning Surveys to Detect Specified Population Changes

The precision of both population estimates influences your ability to detect a given change; therefore, control over precision of estimates is necessary when attempting to detect specified changes. To determine precision needed to detect a change, first specify the CD, i.e., the minimum difference to be detected. Then decide how sure you must be that a change equal to or greater than CD occurred before you will conclude that there was a change. If one needs to be 95% sure that a change occurred, the acceptable error for this type of conclusion is 5%, giving $\alpha = 0.05$. Next, decide how sure you need to be that any change was less than CD before you will conclude that no consequential change occurred. If you need to be 80% sure that no consequential change occurred, i.e., an 80% probability of detecting a change as large as CD, then the tolerable error for this type of conclusion is 20%, giving $\beta = 0.20$.

Once realistic values for CD, α , and β are established, known and estimated values are entered into an equation and the unknown sampling variance or variances are computed. This process determines the maximum sampling variance that will allow you to detect a change in numbers with required precision. The general form of the equation that describes the relationship among $V(\hat{T}_1)$, $V(\hat{T}_2)$, CD, α , and β is

$$t_{\alpha, \nu} + t_{\beta, \nu} = \frac{CD}{\sqrt{V(\hat{T}_1) + V(\hat{T}_2)}}$$

It is closely related to the t -test formula in Section 4.2.1.2. The changes are that CD is substituted for $\hat{T}_2 - \hat{T}_1$ and $t_{\beta, \nu}$ is added to allow you to guard against a Type II error during the planning phase of your study.

Two possible situations exist for estimating the required precision: (1) when the first survey has been completed, which fixes the precision required for the second survey, and (2) when neither survey has been completed. Each of these is discussed below. Note that within each of these situations either a one-tailed or a two-tailed test can be used, depending upon the nature of the experiment and hypotheses (see Sections 4.2.1.2 and 4.2.1.4). Select the appropriate t -value for the type of test (Tables 8, 14).

4.2.2.1 Estimating required precision of second estimate when first survey is completed

Determine the maximum allowable sampling variance of the second population estimate, $V(\hat{T}_2)$, as follows:

$$V(\hat{T}_2) = \frac{CD^2}{(t_{\alpha, \nu} + t_{\beta, \nu})^2} - V(\hat{T}_1).$$

This is the general equation (Section 4.2.2) solved for $V(\hat{T}_2)$. For example, assume you want to detect a 40% increase in population size, based on the first estimate \hat{T}_1 . You want to be 90% certain that you are correct if you conclude that an increase of 40% occurred ($\alpha = 0.1$), and you would be satisfied with 80% probability of detecting an increase, if it occurred, ($\beta = 0.2$). Data for the first estimate were $\hat{T}_1 = 2,000$, $V(\hat{T}_1) = 90,000$, and $v_{e1} = 12$. A 40% increase makes $CD = 800$. Because you are only interested in testing for a population increase, use a one-tailed test. The final v_t cannot be accurately estimated at this point. The adjusted v_t will be at least as large as v_{e1} for the first estimate, and an error in estimating v_t of that size will have little effect on the t -value or the estimated required precision. Therefore, use v_{e1} from the first estimate, which is $v_{e1} = 12$ in this example.

Solving the example problem, where $t_{\alpha, \nu} = 1.356$ and $t_{\beta, \nu} = 0.873$, produces

$$V(\hat{T}_2) = \frac{800^2}{(1.356 + 0.873)^2} - 90,000 = 38,813.$$

Therefore, when making the second estimate, a sampling variance equal to or less than 38,813 must be obtained if a 40% increase is to be detected with $\alpha = 0.1$ and $\beta = 0.2$. If the population increase is larger than 40%, a significant change can be detected with a variance greater than 38,813.

Commonly, β is not considered in statistical tests. In effect, β becomes 0.5, at which $t_{\beta} = 0$, i.e., there is a 50:50 chance of detecting a change if it occurred. Note that in the above equation t_{α} and t_{β} are additive; as the probability of making a Type II error decreases the sum of the t -values increases. The larger the t -value, the greater precision required to detect a change. Increased precision translates into increased dollars. We believe the increased cost often prevents biologists from incorporating Type II error consideration in statements of required precision. Additionally, lack of appreciation for the consequences of Type II errors and the lack of understanding of interrelationships between Types I and II errors are probably major causes for neglect of β specification.

4.2.2.2 Estimating required precision before making the first of two population estimates

Because sampling variances $V(\hat{T}_1)$ and $V(\hat{T}_2)$ are additive in the formula,

$$t_{\alpha, \nu} + t_{\beta, \nu} = \frac{CD}{\sqrt{V(\hat{T}_1) + V(\hat{T}_2)}}$$

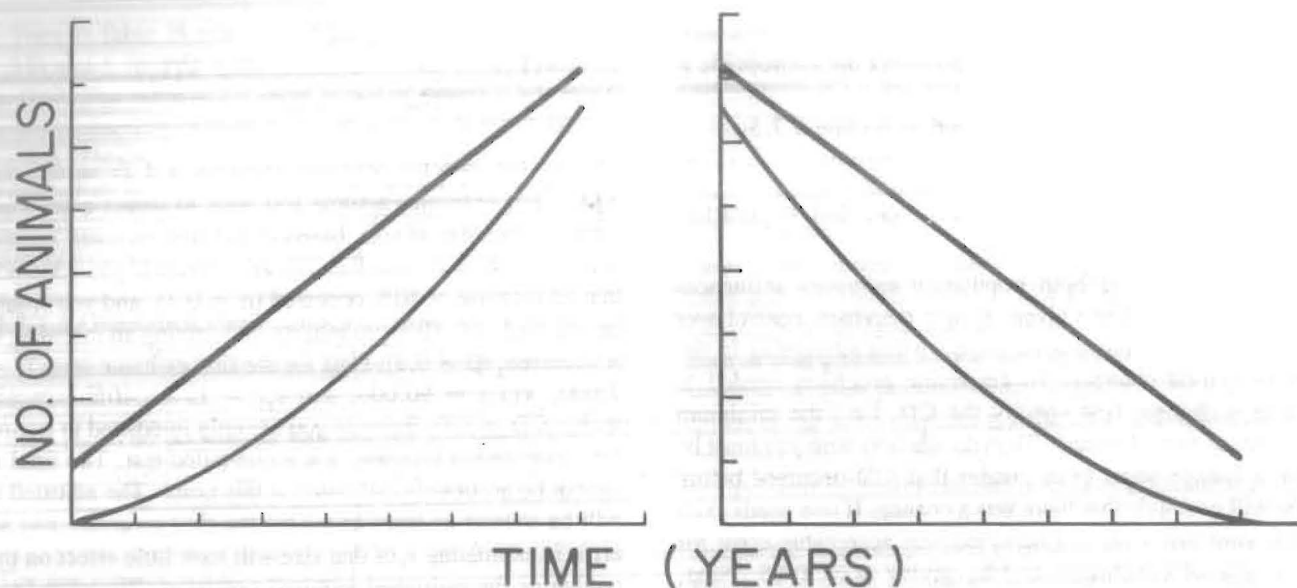


Figure 21. Generalized curves for population growth and decline models.

the maximum total variance is estimated when planning two surveys that will detect specified differences between population estimates. This variance is then subjectively allocated between the two estimates of \hat{T}_1 and \hat{T}_2 . In theory, it should not matter whether the variance is larger or smaller for the first estimate. However, in practice, strive for about half the total variance in each estimate or slightly over half for the one you think will be higher. Avoid allowing such a large sampling variance on the first survey that an unobtainably small sampling variance is required for the second estimate.

Solve the equation for the total variance,

$$V(\hat{T}_1) + V(\hat{T}_2) = \frac{CD^2}{(t_{\alpha, \nu} + t_{\beta, \nu})^2}.$$

The t -values are dependent on the probability levels selected, the estimated ν , and the hypothesis being tested, i.e., one-tailed or two-tailed tests.

This method of estimating precision is useful only in the planning stages. As soon as the first population survey is in progress (before completion), the required precision should be reevaluated using the tentative estimates \hat{T}_1 and $V(\hat{T}_1)$ (Section 4.2.2.1).

4.3 ESTIMATING RATE OF POPULATION CHANGE

Rate of change reflects the net increase or decrease in a population after recruitment and mortality. Rate of change is one of the more valuable figures that managers can obtain. It measures the success or failure of management actions and forecasts the short-term future of the population, assuming constancy of controlling factors. However, rate of change estimates are subject to substantial error because

they are based on population estimates that contain sampling errors and sometimes bias. Assumptions also have to be made on the shape of the population growth curve between estimates.

The accuracy of the estimated rate of change depends, in part, on choosing the appropriate model. The two most common population growth and decline models are the exponential and linear (Fig. 21), of which the exponential is probably most widely used. See Caughley (1977) for a good discussion of growth rate.

Plotting a data set with three or more population estimates will assist in selecting the model most closely fitting that data set. First, plot on straight numerical scales. If data show a curve, plot on semilog paper or plot the \log_e of population size against time in years (Fig. 22). The log transformation of numbers of moose (Fig. 22c) will straighten exponential growth or decline.

Choose the best fitting model and estimate rate of change using the appropriate estimator. If there are only two estimates of population size, choose a model based on what shape you think the curve is. Trend, recruitment, and mortality data help in making the decision.

Population estimates must be significantly different for an estimated rate of change to have meaning. See Section 4.2.1 for method of calculating the test statistic.

4.3.1 Exponential Model

A population exhibiting exponential change grows or declines at a constant rate, i.e., the number of animals added or lost varies among time periods, but that number, as a percentage of population size, is constant. The observed exponential rate of change is defined here as \hat{r} . The simplest case for calculating \hat{r} is where only two population estimates exist. Here,

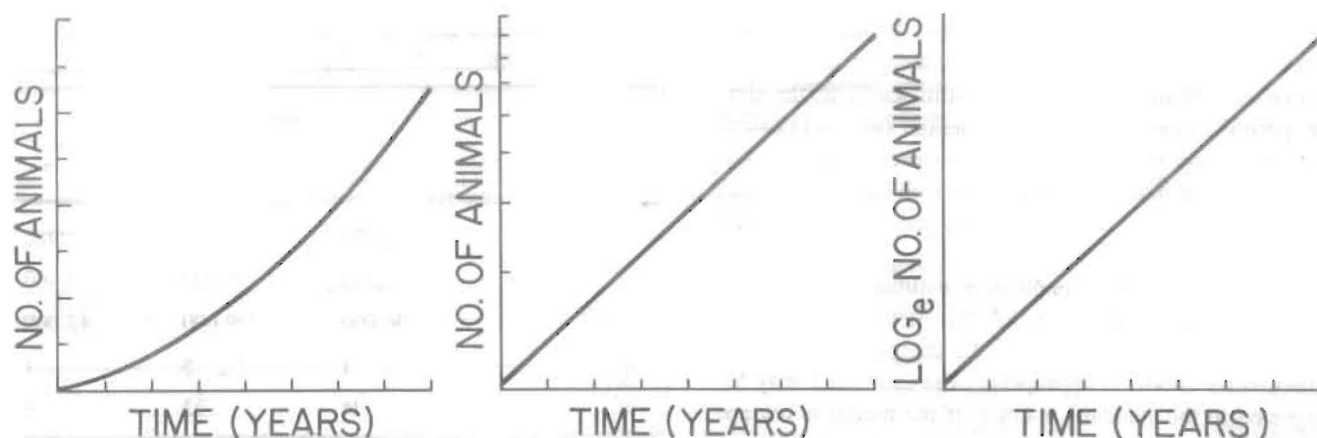


Figure 22. Plotting population estimates in graph (a), on a log scale (b), or as a log transformation (c) straightens exponential growth curves.

$$\hat{r} = \frac{\log_e \hat{T}_2 - \log_e \hat{T}_1}{\text{no. years between estimates}}$$

where \hat{T}_1 is the initial population estimate, \hat{T}_2 is the second population estimate, and \log_e indicates taking the natural logarithm of \hat{T}_i , where $i = 1, 2$. For example, if $\hat{T}_1 = 2,000$, $\hat{T}_2 = 3,000$, and there was a 4-year interval between estimates, then

$$\begin{aligned} \hat{r} &= \frac{\log_e 3,000 - \log_e 2,000}{4} \\ &= \frac{8.006 - 7.601}{4} \\ &= 0.101. \end{aligned}$$

The \log_e can be easily calculated on most scientific pocket calculators. Commonly, the symbol \ln is used for \log_e on these calculators. Be sure not to use common logarithms.

The precision of \hat{r} can be estimated. Because \hat{T}_1 and \hat{T}_2 are estimates rather than exact counts of numbers of moose, \hat{r} also has an error component.

Calculating variance and confidence intervals for \hat{r} is facilitated by defining

$$L_1 = \log_e \hat{T}_1$$

and approximating

$$V(L_1) = \log_e \left(\frac{V(\hat{T}_1)}{\hat{T}_1^2} + 1 \right)$$

where the variance formula is based on the variance estimate transformation for log normally distributed data (Pritsker 1974). Then

$$V(\hat{r}) = \frac{V(L_1) + V(L_2)}{\Delta_t^2}$$

where Δ_t is the number of years between estimates. To construct a confidence interval, we need to calculate the degrees of freedom for \hat{r} :

$$\nu_r = \frac{[V(L_1) + V(L_2)]^2}{\frac{V(L_1)^2}{\nu_{e1}} + \frac{V(L_2)^2}{\nu_{e2}}}$$

From the example above, suppose $V(\hat{T}_1) = 96,000$, $V(\hat{T}_2) = 139,000$, $\nu_{e1} = 14$, and $\nu_{e2} = 22$. Then $L_1 = 7.601$ and $L_2 = 8.006$ with variances of

$$V(L_1) = \log_e \left(\frac{96,000}{2,000^2} + 1 \right) = 0.0237,$$

and

$$V(L_2) = \log_e \left(\frac{139,000}{3,000^2} + 1 \right) = 0.0153.$$

The variance of \hat{r} is

$$V(\hat{r}) = \frac{0.0237 + 0.0153}{4^2} = \frac{0.0390}{4^2} = 0.00244.$$

To calculate a confidence interval, degrees of freedom are needed.

$$\nu_r = \frac{(0.0390)^2}{\frac{0.0237^2}{14} + \frac{0.0153^2}{22}} \cong 30$$

From Table 8, $t_{0.10,30} = 1.697$. Therefore, a 90% CI for \hat{r} is

$$\hat{r} \pm t_{\alpha, \nu_r} \sqrt{V(\hat{r})}$$

or $0.101 \pm 1.697 \sqrt{0.00244}$ or 0.101 ± 0.084 .

When more than two population estimates exist, the simplest method of estimating the exponential rates is to calculate \hat{r} using only the first and last estimates. The obvious drawback is that interim estimates have no influence on the rate of change; the estimated rate depends solely on the precision of two estimates.

A method that uses all population estimates is based on weighted regression. While useful, this method assumes the aptness of an exponential model for the population being studied. If the model is appropriate, the estimate \hat{r} may be interpreted in the standard manner. If the model is not appropriate over the course of the study (due perhaps to changing population dynamics) the estimate \hat{r} will be a weighted average of exponential growth rates over the course of the study.

Be aware that the method we present will yield different results from a linear regression of L_i on t_i . The variance of \hat{r} ($V(\hat{r})$) that we present is based on the sampling variances of the population estimates whereas the variance of an estimate of r from the linear regression is based on the deviations of observed population estimates from the fitted growth curve.

To estimate \hat{r} from several population estimates (\hat{T}_i), a variable representing time, t_i , is assigned to each population estimate. Generally, t_i is in terms of years, and $t_1 = 1$. For example, if \hat{T}_1 was made in 1976, \hat{T}_2 in 1980, and \hat{T}_3 in 1982, then the values of t_i would be $t_1 = 1$, $t_2 = 5$, and $t_3 = 7$.

For each \hat{T}_i , values for L_i and $V(L_i)$ are calculated as defined above. Then, for each population estimate, calculate

$$a_i = \frac{1}{\sqrt{V(L_i)}},$$

$$b_i = \frac{t_i}{\sqrt{V(L_i)}},$$

and

$$c_i = \frac{L_i}{\sqrt{V(L_i)}}.$$

From these values, calculate $\sum a_i^2$, $\sum b_i^2$, $\sum a_i b_i$, and then for each population estimate calculate

$$d_i = (\sum a_j^2) b_i - (\sum a_j b_j) a_i.$$

The estimate \hat{r} is calculated

$$\hat{r} = \frac{\sum d_i c_i}{(\sum a_i^2)(\sum b_i^2) - (\sum a_i b_i)^2},$$

and its variance is

Table 17. Example data used to calculate the exponential rate of change for a moose population.

Parameter	Estimate		
	1	2	3
Year	1976	1980	1982
\hat{T}_i	2,000	3,000	3,400
$V(\hat{T}_i)$	96,000	139,000	42,000
t_i	1	5	7
v_{ei}	14	22	9

$$V(\hat{r}) = \frac{\sum d_i^2}{[(\sum a_i^2)(\sum b_i^2) - (\sum a_i b_i)^2]}.$$

The degrees of freedom for \hat{r} are

$$\nu_r = \frac{(\sum d_i^2)^2}{\sum \frac{d_i^4}{\nu_{ei}}}$$

For example, \hat{r} , $V(\hat{r})$, and a 90% CI around \hat{r} are calculated from the set of population estimates in Table 17. The calculations are presented with as many as 10 digits of accuracy because the final estimate is sensitive to roundoff of intermediate values. First calculate L_i , $V(L_i)$, a_i , b_i , and c_i for each estimate (Table 18). Then calculate d_i for each estimate with

$$\sum a_i^2 = 383.172514,$$

$$\sum b_i^2 = 15,185.6219,$$

and

$$\sum a_i b_i = 2,298.72562.$$

The estimate of \hat{r} is

$$\begin{aligned} \hat{r} &= \frac{(-613,914.946) + (-200,004.196) + (859,903.947)}{(383.172514)(15,185.6219) - (2,298.72562)^2} \\ &= \frac{45,984.805}{534,573.44} = 0.086 \end{aligned}$$

and

$$V(\hat{r}) = \frac{(-12,438.51748)^2 + (-3,092.59834)^2 + (6,368.12086)^2}{(534,573.44)^2}$$

Table 18. Example parameter estimates used to calculate the exponential rate of change for a moose population.

Parameter	Estimate		
	1	2	3
Year	1976	1980	1982
L_i	7.60090246	8.00636757	8.13153071
$V(L_i)$	0.02371653	0.01532639	0.00362663
a_i	6.4934339	8.0775576	16.6060499
b_i	6.4934339	40.3877880	116.2423493
c_i	49.3559580	64.6718952	135.0326047
d_i	-12,438.51748	-3,092.59834	6,368.12086

$$= \frac{204,833,844.9}{285,768,762,800} = 0.000717.$$

The degrees of freedom are

$$\nu = \frac{(204,833,844.9)^2}{\frac{(-12,438.51748)^4}{14} + \frac{(-3,092.59834)^4}{22} + \frac{(6,368.12086)^4}{9}}$$

$$= 22.1 \cong 22.$$

A 90% CI for \hat{r} is

$$\hat{r} \pm t_{0.10, 22} \sqrt{V(\hat{r})}$$

$$0.086 \pm 1.717 \sqrt{0.000717}$$

$$0.086 \pm 0.046.$$

A rate of increase that is closely related to the exponential rate is the finite rate of change (λ). The estimated finite rate of change is the ratio of population size in year 1 to population size 1 year later.

$$\hat{\lambda} = \frac{\hat{T}_{i+1}}{\hat{T}_i}$$

where i is time in years. For example, in 1980 and 1981, population estimates were 2,000 and 2,500, respectively, and

$$\hat{\lambda} = \frac{2500}{2000} = 1.25.$$

When estimating λ over a time interval of 2 or more years, a constant rate of increase is assumed, as for exponential rate r . For example, in year 1, the population equaled T_1 and 3 years later the population equaled T_4 . The growth sequence was as follows:

$$\begin{array}{cccc} \text{Year:} & 1 & 2 & 3 & 4 \\ \text{Size:} & T_1 & T_1\lambda & T_1\lambda^2 & T_1\lambda^3 = T_4 \end{array}$$

or

$$\begin{aligned} T_1\lambda &= T_2 \\ T_2\lambda &= T_3 \\ T_3\lambda &= T_4 \end{aligned}$$

where λ is simply the annual growth multiplier.

The simplest way to estimate λ when the interval between population estimates exceeds 1 year is to estimate r (as in this Section), and then calculate

$$\hat{\lambda} = e^{\hat{r}}$$

on a suitable pocket calculator. The constant e equals 2.7183. Using the example earlier in this section where $\hat{r} = 0.101$, the finite rate of change is

$$\hat{\lambda} = e^{\hat{r}} = e^{0.101} = 1.106.$$

The population increased 1.106 times each year, equivalent to 10.6% compounded annually.

The annual percentage change is calculated as follows:

$$\% \text{ change} = (\hat{\lambda} - 1)100.$$

For example, when a population is increasing at a finite rate = 1.106, the

$$\begin{aligned} \% \text{ change} &= (1.106 - 1)100 \\ &= 0.106 \times 100 = 10.6. \end{aligned}$$

When the population is declining, the percentage change becomes negative. For example, when a population is de-

clining at the same rate as the one in the above example is increasing (i.e., $\hat{r} = 0.101$), then

$$\hat{r} = -0.101$$

and

$$\hat{\lambda} = e^{\hat{r}} = 0.904.$$

The percentage change is

$$\begin{aligned}\% \text{ change} &= (0.904 - 1)100 \\ &= -0.096 \times 100 = -9.6.\end{aligned}$$

Note that with r , equal rates of increase and decrease are symmetrical around 0.0 and differ only by a + or - sign. In contrast, with λ , equal rates of increase and decrease are not symmetrical around 1.0 and both are positive (percentage changes calculated from λ do have + and - signs, however). Therefore, comparison using finite rates of change can be more difficult to quickly interpret than exponential rates; however, all things considered, finite rates are generally easier for people to work with and visualize. To calculate a confidence interval around $\hat{\lambda}$, first calculate the CI for \hat{r} . Let

$$\hat{r}_+ = \hat{r} + t_{\alpha, \nu} \sqrt{V(\hat{r})}$$

and

$$\hat{r}_- = \hat{r} - t_{\alpha, \nu} \sqrt{V(\hat{r})}.$$

The upper confidence limit for $\hat{\lambda}$ is

$$\hat{\lambda}_+ = e^{\hat{r}_+}$$

and the lower limit is

$$\hat{\lambda}_- = e^{\hat{r}_-}.$$

4.3.2 Linear Model

With linear change, a population grows or declines by a constant number of animals each year. However, the growth rate of an increasing population declines because the constant number is an ever-decreasing proportion of the increasing population. Conversely, in a declining population, the rate of decline increases each year because the constant number is an ever-increasing proportion of the declining population. You can easily demonstrate this by plotting hypothetical data sets that change annually by a constant number and calculating the percentage change for each 1 year interval.

To estimate the annual linear rate of change in population size (\hat{g}) between two estimates, calculate

$$\hat{g} = \frac{\hat{T}_2 - \hat{T}_1}{\Delta_t}$$

The variance of \hat{g} is

$$V(\hat{g}) = \frac{V(\hat{T}_1) + V(\hat{T}_2)}{\Delta_t^2}.$$

The number of degrees of freedom is

$$\nu_g = \frac{[V(\hat{T}_1) + V(\hat{T}_2)]^2}{\frac{[V(\hat{T}_1)]^2}{\nu_1} + \frac{[V(\hat{T}_2)]^2}{\nu_2}}.$$

To estimate g from more than two population estimates, assign a t_i to each \hat{T}_i as in Section 5.2.1. Then for each \hat{T}_i , calculate

$$a_i = \frac{1}{\sqrt{V(\hat{T}_i)}},$$

$$b_i = \frac{t_i}{\sqrt{V(\hat{T}_i)}},$$

and

$$c_i = \frac{\hat{T}_i}{\sqrt{V(\hat{T}_i)}}.$$

Calculate $\sum_i a_i^2$, $\sum_i b_i^2$, and $\sum_i a_i b_i$, and then for each \hat{T}_i calculate

$$d_i = (\sum_j a_j^2) b_i - (\sum_j a_j b_j) a_i.$$

The estimate (\hat{g}) is then calculated

$$\hat{g} = \frac{\sum_i d_i c_i}{(\sum_i a_i^2)(\sum_i b_i^2) - (\sum_i a_i b_i)^2},$$

and its variance is

$$V(\hat{g}) = \frac{\sum_i d_i^2}{[(\sum_i a_i^2)(\sum_i b_i^2) - (\sum_i a_i b_i)^2]^2}$$

with degrees of freedom

$$\nu_g = \frac{(\sum_i d_i^2)^2}{\sum_i \frac{d_i^4}{\nu_{ei}}}.$$

4.3.3 Suggested Frequency of Estimating Population Size

From an economic view, successive population estimates should be separated by sufficient time to allow a detectable

change to occur. The precision level of population estimates does not allow annual changes to be detected, except when there is catastrophic mortality. The minimum interval for detectable population change may be as little as 2 years or

more than 5 years, depending on the dynamics of the specific population. Population estimates are expensive and their infrequent use will minimize expense and assure efficiency.

5. ESTIMATING SEX AND AGE COMPOSITION OF POPULATIONS

5.1 INTRODUCTION

Sex and age composition estimates for moose populations are confounded by moose behavior (Linkswiler 1982, Gasaway et al. 1985). Moose segregate by sex and age classes (Peek et al. 1974) and some classes are more difficult to see than others. Therefore, biases occur with subjective selection of sampled areas and not observing moose in sampled areas. Nevertheless, composition data, which had relatively constant bias, have been used to signal changes in moose population dynamics. Thus, composition estimates altered by bias may not materially affect the interpretation of some population changes. However, with representative composition data (unbiased sampling) and population estimates, numbers of calves, yearlings, adult bulls, and adult cows can be estimated. These data are valuable for estimating recruitment, setting hunting seasons for specific cohorts, and modeling population dynamics.

The following method of estimating composition has minimum bias because areas to be searched during the survey are randomly selected and the prescribed search intensity allows you to see a high percentage of moose in the SUs searched. Population composition is calculated for each stratum in the survey area, and overall composition is calculated by summing strata estimates.

Numbers of moose in particular sex-age classes and composition ratios may be estimated from survey data if moose observed during standard searches are classified into sex and age classes. Form 8 summarizes composition data from SUs (see Appendix 2 for blank form).

5.2 ESTIMATING NUMBER OF MOOSE IN SEX AND AGE CLASSES

5.2.1 Definition of Symbols

w_j = number of moose in a sex-age class observed in the j th SU

w = as a subscript, denotes that the parameter is calculated for a specific sex-age class

\hat{W}_i = stratum population estimate of moose in a sex-age class.

All other symbols are defined in Section 3.7.1.1.

5.2.2 Step 1.—Calculating the Observable Stratum Sex-age Class Estimate and Its Sampling Variance

Estimates of numbers of moose in sex-age classes are calculated using procedures similar to population estimates in Section 3.7.1. The observable stratum estimate of bulls, for example, is the number of bulls that could have been seen if the entire stratum had been searched with the stand-

ard search effort (e.g., 4 to 6 min/mi² in early winter). For the i th strata, estimate the number of observable moose in the sex-age class (\hat{W}_i) by calculating

$$\hat{W}_i = \text{density of sex-age class} \times \text{area of stratum}$$

or

$$\hat{W}_i = d_{iw} \cdot A_i$$

where

$$d_{iw} = \frac{\text{total number of moose in the sex-age class observed in all SUs surveyed in the } i\text{th stratum}}{\text{total surface area of all SUs surveyed in the } i\text{th stratum}}$$

or

$$d_{iw} = \frac{\sum_j w_j}{\sum_j x_j}$$

The sampling variance of \hat{W}_i is

$$V(\hat{W}_i) = A_i^2 \left[\frac{1}{\bar{x}_i^2} \times \frac{s_{qiw}^2}{n_i} \left(1 - \frac{n_i}{N_i} \right) \right]$$

where

$$s_{qiw}^2 = \frac{\sum_j w_j^2 - 2d_{iw} \sum_j x_j w_j + d_{iw}^2 \sum_j x_j^2}{n_i - 1}$$

5.2.3 Step 2.—Calculating the Observable Sex-age Class Estimate and Its Sampling Variance for the Survey Area

The observable sex-age class estimate for the survey area (\hat{W}_o) is the summation of the strata estimates, uncorrected for sightability.

$$\hat{W}_o = \hat{W}_h + \hat{W}_m + \hat{W}_l$$

and the sampling variance is the sum of sampling variances of observable stratum sex-age class estimates, or

$$V(\hat{W}_o) = V(\hat{W}_h) + V(\hat{W}_m) + V(\hat{W}_l)$$

where h , m , and l are the high-, medium- and low-density strata, respectively. Degrees of freedom are calculated as

$$\nu_{ow} = \frac{[V(\hat{W}_o)]^2}{\frac{[V(\hat{W}_h)]^2}{n_h - 1} + \frac{[V(\hat{W}_m)]^2}{n_m - 1} + \frac{[V(\hat{W}_l)]^2}{n_l - 1}}$$

5.2.4 Step 3.—Calculating the Expanded Sex-age Class Estimate and Its Sampling Variance

The observable sex-age class estimate for the survey area is multiplied by the observed sightability correction factor (Section 3.6.5.1) to produce the expanded sex-age class estimate (\hat{W}_e).

$$\hat{W}_e = \hat{W}_o \cdot SCF_o$$

with a sampling variance

$$V(\hat{W}_e) = (SCF_o^2)V(\hat{W}_o) + (\hat{W}_o^2)V(SCF_o) - V(\hat{W}_o)V(SCF_o)$$

and degrees of freedom

$$v_{ew} = \text{minimum of } [v_{ow}, v_s],$$

Where v_{ew} is the smaller of the two values, v_{ow} or v_s .

5.2.5 Step 4.—Calculating the Total Sex-age Class Estimate and Its Variance

The expanded sex-age class estimate (\hat{W}_e) is multiplied by the sightability correction factor constant (SCF_c) to produce the total sex-age class population estimate (\hat{W}).

$$\hat{W} = \hat{W}_e \cdot SCF_c$$

with a sampling variance

$$V(\hat{W}) = (SCF_c)^2 V(\hat{W}_e).$$

5.2.6 Step 5.—Calculating the Confidence Interval of the Total Sex-age Class Estimate

The CI for \hat{W} is calculated as

$$CI = \text{total sex-age class estimate} \pm t_{\alpha, \nu} \sqrt{\text{variance of total sex-age class estimate}}$$

or

$$CI = \hat{W} \pm t_{\alpha, \nu} \sqrt{V(\hat{W})}$$

where degrees of freedom $\nu = v_{ew}$, and Student's t -values are found in Table 8.

5.3 EXAMPLE: ESTIMATING NUMBER OF MOOSE IN A SEX-AGE CLASS

The following example is a step-by-step procedure for calculating the number of cows for the Square Mountain survey area. Data used include data in Table 19 and the following sightability data: $SCF_o = 1.08$, $V(SCF_o) = 0.003400$, $SCF_c = 1.02$, and $v_s = 9$. Calculations for the

number of cows in the medium stratum are presented in detail. Refer to Section 5.2 for formulae while working through calculations in this section.

5.3.1 Step 1.—Calculating the Observed Stratum Estimate and Its Sampling Variance for Cows

5.3.1.1 Low-density stratum estimates

Density estimate:

$$d_{tw} = 0.082508 \text{ cows/mi}^2.$$

Observed stratum estimate:

$$\hat{W}_t = 23 \text{ cows.}$$

Sampling variance estimate:

$$V(\hat{W}_t) = 76.941.$$

5.3.1.2 Medium-density stratum estimates

Density estimate:

$$\begin{aligned} d_{mw} &= \frac{40 \text{ cows seen in medium stratum SUs}}{71.6 \text{ mi}^2 \text{ surveyed in medium stratum}} \\ &= 0.558659 \text{ cows/mi}^2. \end{aligned}$$

Observed cow estimate:

$$\begin{aligned} \hat{W}_m &= 0.558659 \text{ cows/mi}^2 \times 240.2 \text{ mi}^2 \text{ stratum area} \\ &= 134 \text{ cows.} \end{aligned}$$

Sampling variance estimate:

First solve for s_{qmw}^2 .

$$\begin{aligned} s_{qmw}^2 &= \frac{324 - [2(0.558659)495.80] + [(0.558659)^2(861.74)]}{6 - 1} \\ &= 7.815965. \end{aligned}$$

Use the value of s_{qmw}^2 to solve for $V(\hat{W}_m)$.

$$V(\hat{W}_m) = 240.2^2 \left[\frac{1}{11.93^2} \times \frac{7.815962}{6} \left(1 - \frac{6}{20} \right) \right] = 368.528.$$

5.3.1.3 High-density stratum estimates

Density estimate:

$$d_{hw} = 1.405258 \text{ cows/mi}^2.$$

Table 19. Composition data collected during a fictitious survey of the Square Mountain survey area.

Stratum	No. of SUs ^a	Moose observed			SU area (mi ²)	Total stratum area (mi ²)	Total SUs in stratum
		Bulls	Cows	Calves			
Low	1	0	2	0	12.4	277.7	23
	2	2	0	0	10.9		
	3	1	0	0	12.9		
	4	1	2	1	13.1		
	5	0	1	0	11.3		
Medium	1	3	4	2	11.5	240.2	20
	2	7	5	2	11.2		
	3	7	12	3	14.3		
	4	5	3	2	11.0		
	5	3	9	5	12.0		
	6	3	7	2	11.6		
High	1	14	25	10	14.7	158.9	13
	2	9	33	15	15.0		
	3	10	22	9	12.0		
	4	6	15	2	10.7		
	5	18	9	5	10.3		
	6	2	4	0	11.9		
	7	9	18	8	13.4		
	8	18	14	3	11.4		
	9	4	15	0	10.9		

^aSU equals sample unit.

Observed cow estimate:

$$\hat{W}_h = 223 \text{ cows.}$$

Sampling variance estimate:

$$V(\hat{W}_h) = 275.910.$$

5.3.2 Step 2.—Calculating the Observed Cow Estimate and Its Sampling Variance for the Survey Area

Observed cow estimate:

$$\hat{W}_o = 223 \text{ in high stratum} + 134 \text{ in medium stratum} + 23 \text{ in low stratum}$$

$$= 380 \text{ cows.}$$

Sampling variance estimate:

$$V(\hat{W}_o) = 275.910 \text{ high stratum} + 368.528 \text{ medium stratum} + 76.941 \text{ low stratum}$$

$$= 721.379.$$

Degrees of freedom:

$$v_{ow} = \frac{(721.379)^2}{\frac{(275.910)^2}{9-1} + \frac{(368.528)^2}{6-1} + \frac{(76.941)^2}{5-1}} \cong 14.$$

5.3.3 Step 3.—Calculating the Expanded Cow Estimate and Its Sampling Variance

Expanded cow estimate:

$$\hat{W}_e = 380 \text{ cows} \times \text{SCF}_o \text{ of } 1.08 = 410.$$

Sampling variance estimate:

$$\begin{aligned} \hat{W}_e &= 1.08^2(721.379) + 380^2(0.003400) \\ &\quad - 721.379(0.003400) \\ &= 1329.924. \end{aligned}$$

Degrees of freedom:

$$v_{ew} = \text{minimum of } [14, 9] = 9.$$

5.3.4 Step 4.—Calculating the Total Cow Estimate and Its Sampling Variance

Total cow estimate:

$$\hat{W} = 410 \text{ cows} \times \text{SCF}_e \text{ of } 1.02 = 418 \text{ cows.}$$

Sampling variance estimate:

$$V(\hat{W}) = 1.02^2(1329.924) = 1383.653.$$

5.3.5 Step 5.—Calculating the 90% Confidence Interval for the Total Cow Estimate

Confidence interval:

$$CI = 418 \pm 1.833 \sqrt{1383.653} = 418 \pm 68 \text{ cows.}$$

Confidence limits:

$$CL_u = 486 \text{ cows}$$

$$CL_l = 350 \text{ cows.}$$

5.4 HEWLETT-PACKARD 97 PROGRAM: ESTIMATING NUMBER OF MOOSE IN SEX AND AGE CLASSES

5.4.1 Program Instructions

HP 97 program 1 in Appendix 1 is used both to estimate population size (Section 3.9) and to estimate the number of moose in a sex-age class. However, instead of entering the total number of moose in a SU (y_j), enter the number of moose in a sex-age class in a SU (w_j). The total number of moose in a sex-age class is then estimated (\hat{W}), instead of the total population estimate (\hat{T}).

The HP 97 program instructions in Section 3.9 (Table 10) have been revised by substituting the appropriate statistical symbols and eliminating unnecessary portions of the program (Table 20). The calculator display, which appears after a function key is depressed, indicates the step in the program and indicates the calculator is ready for data or an action appropriate for that step. For example, when the calculator display is “- III.”, you are at step 3 and need to press function key D.

5.4.2 Program Printout

The HP 97 printout format shown in Figure 23 uses data from the example in Section 5.3. The HP 97 prints only numbers and asterisks. Three asterisks are normally printed at the right of each number; asterisks have been omitted in this example to conserve space. Symbols were added in this example to facilitate the identification of each number.

5.5 ESTIMATING SEX AND AGE RATIOS

Composition ratios are calculated using estimates of observable moose from two sex-age classes. Each ratio has a numerator sex-age class and a denominator sex-age class. In an estimate of calves/cows, “calves” is the numerator class and “cows” is the denominator class. In estimating the proportion of a population that is “cows,” or “cows/total

moose,” “cows” is the numerator class and “total moose” is the denominator class.

Let w_{jn} be the number of moose in the numerator sex-age class observed in the j th SU and let w_{jd} be the number of moose in the denominator sex-age class observed in the j th SU. The estimated observable moose in the numerator and denominator classes is calculated as in the previous section (5.2).

The estimate of the composition ratio (\hat{p}) is

$$\hat{p} = \frac{\sum_i \hat{W}_{in}}{\sum_i \hat{W}_{id}} = \frac{\hat{W}_{on}}{\hat{W}_{od}}.$$

An approximation for the sampling variance of \hat{p} requires \hat{W}_{on} , \hat{W}_{od} , $V(\hat{W}_{on})$, and $V(\hat{W}_{od})$, which can be calculated by methods previously given, plus the $\text{Cov}(\hat{W}_{in}, \hat{W}_{id})$ for each stratum. $\text{Cov}(\hat{W}_{in}, \hat{W}_{id})$ is calculated as

$$\text{Cov}(\hat{W}_{in}, \hat{W}_{id}) = A_1^2 \left[\frac{1}{\bar{x}_1^2} \times \frac{s_{qind}}{n_1} \left(1 - \frac{n_1}{N_1} \right) \right]$$

where (Cochran 1977)

$$s_{qind} = \frac{\sum_j w_{jn} w_{jd} - d_{in} \sum_j x_j w_{jd} - d_{id} \sum_j x_j w_{jn} + d_{in} d_{id} \sum_j x_j^2}{n_1 - 1}$$

The sampling variance of \hat{p} is calculated

$$V(\hat{p}) = \hat{p}^2 \left[\frac{V(\hat{W}_{on})}{\hat{W}_{on}^2} + \frac{V(\hat{W}_{od})}{\hat{W}_{od}^2} - \frac{2 \sum_i \text{Cov}(\hat{W}_{in}, \hat{W}_{id})}{\hat{W}_{on} \hat{W}_{od}} \right]$$

and the degrees of freedom are

$$\nu_p = \text{minimum} [\nu_{own}, \nu_{owd}].$$

It is sometimes preferable to present a composition ratio as numerator moose/100 denominator moose, e.g., calves/100 cows, rather than calves/cow. By calculating

$$\hat{p}_{100} = 100\hat{p}$$

and

$$V(\hat{p}_{100}) = 10,000V(\hat{p}),$$

the ratio can be presented as \hat{p}_{100} numerator animals/100 denominator animals.

A CI for \hat{p}_{100} is calculated

$$CI = \hat{p}_{100} \pm t_{\alpha, \nu} \sqrt{V(\hat{p}_{100})}$$

where degrees of freedom $\nu = \nu_p$ and Student's t -values are found in Table 8.

Table 20. Hewlett-Packard 97 program instructions for calculating the estimated number of moose in sex and age classes.

Step	Display value equals	Instruction	Printout value equals
1	0.00	LOAD both sides of card 1	
2	0.	PRESS A	
3	-111.	PRESS D	
4	-222.	ENTER SCF_o (observed sightability correction factor) PRESS R/S	SCF_o
5	SCF_o	ENTER $V(SCF_o)$ (variance of SCF_o) PRESS R/S	$V(SCF_o)$
6	$V(SCF_o)$	ENTER v_s (degrees of freedom of SCF_o) PRESS R/S	v_s
7	-333.	PRESS E	
8	-444.	ENTER A_i (total area for stratum) PRESS R/S [†]	A_i
9	A_i	ENTER N_i (total SUs for stratum) PRESS R/S [†]	N_i
10	0.0 or no. of data sets entered	ENTER w_j (no. moose in a sex and age class counted in SU_j) PRESS R/S ^{†,††}	w_j
11	w_j or no. of data sets entered	ENTER x_j (area of SU_j) PRESS R/S ^{†,††} Repeat steps 10 and 11 until all SUs are entered for a stratum	x_j
12	no. of data sets entered	PRESS f, c	n_i (no. SUs surveyed in stratum) d_{iw} (stratum density) \hat{W}_i (stratum sex-age class population est.) $V(\hat{W}_i)$ (variance)
13	-444.	Choose either: (1) To enter more strata, go to step 8; or (2) If all strata are entered, go to step 14.	
14	-444.	PRESS f, d	\hat{W}_o (observed sex-age est.) $V(\hat{W}_o)$ (variance) v_{ow} (degrees freedom for \hat{W}_o)

Table 20. Continued.

Step	Display value equals	Instruction	Printout value equals
15	-555.	LOAD both sides of card 2	
16	-555.	PRESS A	\hat{W}_e (expanded sex-age est.) $V(\hat{W}_e)$ (variance) ν_{ew} (degrees freedom for \hat{W}_e)
17	-666.	ENTER SCF _c (sightability correction factor constant) PRESS R/S	SCF _c \hat{W} (total sex-age est.) $V(\hat{W})$ (variance)
18	-777.	Choose: (1) To enter new SCF _c , PRESS B, and return to step 17, (2) To calculate 90% CI, PRESS D; or (3) To calculate 95% CI, PRESS E (i.e., $\hat{W} \pm \%$)	% CI selected CI _l (lower confidence limit) CI _u (upper confidence limit) CI as $\pm \%$ of \hat{W}
END OF PROGRAM		To rerun the program it is necessary to return to step 1 and reload card 1	

[†] If an error is made entering A_i or N_i , or if the entry of y_j s and x_j s is in a shambles, all information for current strata can be retracted by pressing E. All previous strata (strata for which f and c were pressed in step 18) will not be affected.

^{††} If an error is made in entering w_j and x_j , finish entering both w_j and x_j until positioned at step 10, then PRESS f and b.
ENTER erroneous w_j , PRESS R/S, and it will be printed.
ENTER erroneous x_j , PRESS R/S, and it will be printed.

You will be positioned again at step 10. Note that the display number is 1 less than previously displayed. Proceed with step 10 and enter correct w_j and x_j .

5.6 EXAMPLE: CALCULATING ESTIMATED SEX-AGE RATIOS

The following example demonstrates the procedure for calculating a bull/cow ratio from data presented in Table 19. The HP 97 program (Section 5.7) calculates ratios from uncorrected estimates (\hat{W}_e) of sex-age population size.

The estimated composition ratio (\hat{p}) is calculated using methods described in Section 5.4. The only calculations that have not been previously described are those for $V(\hat{p})$, which requires calculation of a covariance for each stratum [$\text{Cov}(W_{in}, W_{id})$]. Therefore, values for the observed stratum estimates will be listed but not calculated in this section.

Calculation of covariance for the medium stratum will be demonstrated in detail. Refer to Section 5.5 for formulae while working through calculations in this section.

The values derived in these calculations will vary slightly from the HP 97 program and from your hand calculations because of rounding differences.

5.6.1 Low-density Stratum Estimates

$$\hat{W}_{tn} = 18 \text{ bulls}$$

$$V(\hat{W}_{tn}) = 59.705$$

$$\hat{W}_{td} = 23 \text{ cows}$$

Printout	Symbol	Printout	Symbol	Printout	Symbol
1.08	SCF _o	12.0		13.4	
0.003400	V(SCF _o)	14.3		14.0	
9.	ν_s	3.0		11.4	
		11.0		15.0	
277.7	A _l	9.0		10.9	
23.	N _l	12.0			
		7.0		9.	n _h
2.0	w _j	11.6		1.405258386	d _{hw}
12.4	x _j			223.3	\hat{W}_h
0.0		6.	n _m	275.910	V(\hat{W}_h)
10.9		0.558659218	d _{mw}		
0.0		134.2	\hat{W}_m	380.4	\hat{W}_o
12.9		368.528	V(\hat{W}_m)	721.38	V(\hat{W}_o)
2.0				14.	ν_{ow}
13.1		158.9	A _h		
1.0		13.	N _h	411.	\hat{W}_e
11.3				1331.	V(\hat{W}_e)
5.	n _l	25.0	w _j	9.	ν_{ew}
0.082508251	d _{lw}	14.7	x _j		
22.9	\hat{W}_l	33.0		1.02	SCF _c
76.941	V(\hat{W}_l)	15.0		419.	\hat{W}_c
		22.0		1385.	V(\hat{W}_c)
240.2	A _m	12.0			
20.	N _m	15.0		90.	90% CI
		10.7		351.	CL _l
4.0	w _j	9.0		487.	CL _u
11.5	x _j	10.3		16.3	CI as $\pm\% \hat{W}$
5.0		4.0			
11.2		11.9			
		18.0			

Figure 23. Example of the Hewlett-Packard 97 printout of the program the estimated number of moose in sex and age classes. These data are from Table 19 and estimate the number of cow moose in the Square Mountain survey area. The tape printout has been divided into three columns; complete column 1, proceed to column 2, and finally to 3.

$$V(\hat{W}_{ld}) = 76.941$$

$$\text{Cov}(\hat{W}_{ln}, \hat{W}_{ld}) = -41.812.$$

5.6.2 Medium-Density Stratum Estimates

$$\hat{W}_{mn} = 94 \text{ bulls}$$

$$V(\hat{W}_{mn}) = 158.839$$

$$\hat{W}_{md} = 134 \text{ cows}$$

$$V(\hat{W}_{md}) = 368.528.$$

$$\begin{aligned} s_{qmnd} &= \frac{194 - 0.391061(495.80)}{6 - 1} \\ &+ \frac{-(0.558659)338.80}{6 - 1} \\ &+ \frac{0.391061(0.558659)861.74}{6 - 1} \\ &= -0.168301. \end{aligned}$$

The value of s_{qmnd} is used to solve for $\text{Cov}(\hat{W}_{mn}, \hat{W}_{md})$.

$$\begin{aligned} \text{Cov}(\hat{W}_{mn}, \hat{W}_{md}) &= 240.2^2 \left[\frac{1}{11.93^2} \times \frac{-0.168301}{6} \left(1 - \frac{6}{20} \right) \right] \\ &= -7.959543. \end{aligned}$$

To estimate covariance [$\text{Cov}(\hat{W}_{mn}, \hat{W}_{md})$], first solve for s_{qmnd} .

Table 21. Hewlett-Packard 97 program instructions for calculating estimated sex and age ratios.

Step	Display value equals	Instruction	Printout value equals
1	0.00	LOAD both sides of card 1	
2	0.	PRESS A	
3	-511. or -533.	PRESS B	
4	0 or no. of data sets entered	ENTER w_{jn} (no. moose in the numerator [numer.] sex-age class counted in SU_j) PRESS R/S [†]	w_{jn}
5	w_{jn}	ENTER w_{jd} (no. moose in the demonimator [denom.] sex-age class counted in SU_j) PRESS R/S [†]	w_{jd}
6	w_{jd}	ENTER x_j (area of SU_j) PRESS R/S [†] Repeat steps 4-6 until all SUs in stratum are entered.	
7	No. of data sets entered	PRESS C	
8	-522.	ENTER A_i (total area for stratum) PRESS R/S	A_i
9	A_i	ENTER N_i (total SUs in stratum) PRESS R/S	N_i d_{in} (density in numer.) \hat{W}_{in} (est. observable no. moose in numer.) $V(\hat{W}_{in})$ (variance) d_{id} (density in denom.) \hat{W}_{id} (est. observable no. moose in denom.) $V(\hat{W}_{id})$ (variance) $Cov(\hat{W}_{in}, \hat{W}_{id})$ (covariance)
10	-533.	Choose either: (1) To enter more strata, go to step 3; or (2) If all strata are entered, go to step 11	
11	-533.	LOAD both sides of card 2	

Table 21. Continued.

Step	Display value equals	Instruction	Printout value equals
12	-533.	PRESS A	\hat{W}_{on} (observable moose in numer.) $V(\hat{W}_{on})$ (variance) ν_{wn} (degrees freedom of numer.) \hat{W}_{od} (observable moose in denom.) $V(\hat{W}_{od})$ (variance) ν_{wd} (degrees freedom of denom.) $\Sigma \text{Cov}(\hat{W}_{in}, \hat{W}_{id})$ (summation of strata covariances) \hat{p} (est. ratio of numer. and denom.) $V(\hat{p})$ (variance) ν_p (degrees freedom of \hat{p})
13	-544.	Choose either: (1) 90% CI of \hat{p} , PRESS D, or (2) 95% CI of \hat{p} , PRESS E	% CI selected CI_l (lower confidence limit) CI_u (upper confidence limit) CI as \pm % of \hat{p} (i.e., $\hat{p} \pm \%$)
END OF PROGRAM		To rerun the program it is necessary to return to step 1 and reload card 1.	

[†] If an error is made entering w_{jn} , w_{jd} , or x_j , finish entering all data for SU_j (w_{jn} , w_{jd} , and x_j) until positioned at step 4 again. Then PRESS f, b and ENTER initial w_{jn} (whether erroneous or correct), PRESS R/S, and w_{jn} (erroneous or correct) will be printed, ENTER initial w_{jd} , PRESS R/S, and w_{jd} will be printed, and ENTER initial x_j , PRESS R/S, and x_j will be printed. Now you have removed the series of values for SU_j that contained the error, and you are positioned again at step 4. Notice that the display value has decreased by one because the erroneous values have been extracted. Proceed from step 4 by entering the correct series of values.

5.6.3 High-Density Stratum Estimates

$$\hat{W}_{hn} = 130 \text{ bulls}$$

$$V(\hat{W}_{hn}) = 198.911$$

$$\hat{W}_{hd} = 223 \text{ cows}$$

$$V(\hat{W}_{hd}) = 275.910$$

$$\text{Cov}(\hat{W}_{hn}, \hat{W}_{hd}) = 1.734.$$

5.6.4 Calculating the Estimated Bull/Cow Ratio

$$\hat{p} = \frac{242 \text{ bulls}}{380 \text{ cows}} = 0.636842 \text{ bulls/cow.}$$

Sampling variance estimate:

Printout	Symbol	Printout	Symbol	Printout	Symbol
0.	w_{jn}	3.		18.	
2.	w_{jd}	9.		14.	
12.4	x_j	12.0		11.4	
2.		3.		4.	
0.		7.		15.	
10.9		11.6		10.9	
1.		240.2	A_m	158.9	A_h
0.		20.	N_m	13.	N_h
12.9		0.391061453	d_{mn}	0.815956482	d_{hn}
		93.9	\hat{w}_{mn}	129.7	\hat{w}_{hn}
1.		158.839	$V(\hat{w}_{mn})$	198.911	$V(\hat{w}_{hn})$
2.		0.558659218	d_{md}	1.405258386	d_{hd}
13.1		134.2	\hat{w}_{md}	223.3	\hat{w}_{hd}
		368.528	$V(\hat{w}_{md})$	275.910	$V(\hat{w}_{hd})$
0.		-8.486	$Cov(\hat{w}_{mn}, \hat{w}_{md})$	1.734	$Cov(\hat{w}_{hn}, \hat{w}_{hd})$
1.					
11.3		14.	w_{jn}	242.	\hat{w}_{on}
		25.	w_{jd}	417.	$V(\hat{w}_{on})$
277.7	A_t	14.7	x_j	16.	ν_{wn}
23.	N_t			380.	\hat{w}_{od}
0.066006601	d_{tn}	9.		721.	$V(\hat{w}_{od})$
18.3	\hat{w}_{tn}	33.		14.	ν_{wd}
59.705	$V(\hat{w}_{tn})$	15.0		-49.	$\Sigma Cov(\hat{w}_{tn}, \hat{w}_{id})$
0.082508251	d_{td}				
22.9	\hat{w}_{td}	10.		0.635961418	β
76.941	$V(\hat{w}_{td})$	22.		0.005328062	$V(\beta)$
-41.812	$Cov(\hat{w}_{tn}, \hat{w}_{td})$	12.0		14.	ν_p
3.	w_{jn}	6.		90.	90% CI
4.	w_{jd}	15.		0.507384910	CL_t
11.5	x_j	10.7		0.764537927	CL_u
				20.2	CI as $\pm \% \hat{\beta}$
7.		18.			
5.		9.			
11.2		10.3			
7.		2.			
12.		4.			
14.3		11.9			
5.		9.			
3.		18.			
11.0		13.4			

Figure 24. Example of the Hewlett-Packard 97 printout of the program for calculating estimated sex and age ratios. These data are from Table 19 and estimate the bull/cow ratio. The printout has been divided into three columns; complete column 1, proceed to column 2, and finally to 3.

$$V(\hat{p}) =$$

$$(0.636842)^2 \left[\frac{417}{242^2} + \frac{721}{380^2} - \frac{2[(-41.812)+(-7.959)+1.734]}{242 \times 380} \right]$$

$$= 0.005124.$$

Degrees of freedom:

$$v_p = \text{minimum of } [16, 14] = 14.$$

5.6.5 Calculating the Estimated Bulls/100 Cows

$$\hat{p}_{100} = 100 \times 0.636842$$

$$= 64 \text{ bulls/100 cows.}$$

5.6.6 Calculating the 90% Confidence Interval for the Estimated Bulls/100 Cows

$$CI = 64 \pm 1.761 \sqrt{51.24}$$

$$= 64 \pm 13 \text{ bulls/100 cows.}$$

Confidence limits:

$$CL_u = 77 \text{ bulls/100 cows}$$

$$CL_l = 51 \text{ bulls/100 cows.}$$

5.7 HEWLETT-PACKARD 97 PROGRAM: ESTIMATING SEX AND AGE RATIOS

5.7.1 Program Instructions

HP 97 program 3 in Appendix 1 calculates estimates of: (1) the observable number of moose in each sex-age class, and (2) the ratio of animals between two sex-age classes. Define the desired ratio in terms of the numerator and denominator sex-age classes. For example, to calculate a bull/cow ratio, bulls are in the numerator and cows are in the denominator. Program instructions are in Table 21.

At first glance, it may appear that the HP 97 programs in Section 5.4 and this section will both calculate the number of moose in a sex-age class. This is not the case. Even though this program calculates the observed number of

Table 22. Calves/100 cow moose estimated from composition surveys and population estimation surveys in the same area and at the same time. Total numbers of moose observed are in parentheses.

Game Management Unit	Calves/100 cows	
	Composition survey	Population estimation survey
13	31 (344)	45 (459)
13	23 (1,393)	32 (742)
12	20 (525)	26 (526)

moose (\hat{W}_o) for the numerator and denominator of a ratio, it cannot be used to calculate the total moose in a sex-age class (\hat{W}) because it does not correct \hat{W}_o by SCF_o and SCF_c . Nor does this program calculate $V(SCF_o)$, so it will not calculate a CI for the estimates of numbers. Similarly, the sex-age class estimation program in Section 5.4 will not calculate sex-age ratios or their CIs.

The calculator display listed in Table 21, which appears after a function key is depressed, indicates the step in the program that requires data or an action. For example, when the calculator display is “- 511.”, you are at step 3 and need to press function key B.

5.7.2 Program Printout

The HP 97 printout format shown in Figure 24 uses data from the example in Section 5.6. The HP 97 prints only numbers and asterisks. Three asterisks are normally printed at the right of each number; asterisks have been omitted in this example to conserve space. Symbols were added in this example to facilitate the identification of each number.

5.8 BIAS IN COMPOSITION ESTIMATES

Data from population estimation surveys produce higher and more representative calf/cow ratios than Alaska Department of Fish and Game composition surveys (Table 22). We have found that the calf/cow ratio is inversely related to density within a survey area. Composition surveys focus primarily on high-density portions of the survey area, whereas population estimation surveys randomly select SUs. Therefore, composition survey methods are more biased. So far, we have not detected consistent differences in bull/cow ratios produced by the two survey techniques; however, experimental searches using radio-collared moose indicate bulls are more easily seen than cows. Therefore, if bias exists, lower intensity composition surveys will likely overestimate bulls relative to cows.

6. ESTIMATING RELATIVE ABUNDANCE OF MOOSE

6.1 INTRODUCTION

A rapid, inexpensive measure of relative abundance of moose is obtained by using only the stratification process described for estimating population size (Section 3.4). Stratification allows qualitative judgments of relative density over large areas to be systematically recorded in a form easily used by others—the end product is a moose distribution map showing relative density. This type of information is especially useful for areas where no previous survey has been conducted or where survey coverage is incomplete (e.g., much of Alaska and northern Canada).

6.2 SURVEY METHOD

Stratification is carried out as described for population estimation surveys (Section 3.4). The only variation in the above method is the option to use a 1:250,000 scale map, instead of a 1:63,360, assuming SU boundaries are easily found. The most useful end product is usually a 1:250,000 map delineating regions of relative density and the location and numbers of moose sighted. If 1:63,360 maps are used for stratifying, transfer data to a 1:250,000 map.

We recommend drawing SUs on stratification maps. Stratification is easiest and most accurate when SUs are classified into one of several strata rather than trying to identify actual strata boundaries, i.e., where density changes.

6.3 STRATIFYING AREAS ADJACENT TO SURVEY AREAS

Maximum information on relative abundance can be achieved by extending the stratification of a population estimation survey to adjacent areas following the population estimate. These areas should be stratified by the same crew that stratified the survey area, and stratification should be done immediately upon completion of the population estimate. Stratification should be based on the same moose densities used for the strata in the survey area. If habitat and snow conditions are similar in both areas, a rough estimate of moose abundance can be made by applying the respective estimated strata densities (corrected for sightability) from the surveyed area to the newly stratified area. However, the estimate in the stratified-only area has no statistical validity because it was not sampled.

Rough estimates of moose numbers during early winter can also be made from stratification flights by multiplying the number of moose seen by a range of correction factors. The mean number of moose seen during six early winter stratification flights was 37% (range 27-50%) of the estimated population (Table 23). We included the late winter Alaska Peninsula survey with those from early winter because the SCF in this shrub-dominated habitat was similar to SCF estimates during early winter surveys (Table 7). Dividing 100 by 27 and 50 produces correction factors of

Table 23. Correction factors used to calculate rough estimates of moose population size from numbers of moose seen on stratification flights.

Period and drainage	No. seen on stratification (A)	Estimated no. (B)	Percent of estimated no. seen on stratification	Multiplier correction factor (B ÷ A)
Early winter (Oct-Nov)				
Upper Nowitna	515	1,883	27	3.7
Upper Susitna	581	2,081	28	3.6
Upper Susitna	187	496	38	2.7
Tanana Flats	1,252	3,242	39	2.6
Fortymile	257	630	41	2.5
Late winter (Feb)				
Nushagak ^a	198	1,276	16	6.4
Alaska Peninsula ^b	566	1,129	50	2.0

^a Late winter survey in coniferous-dominated forest area.

^b Late winter survey in shrub-dominated area containing no coniferous trees.

3.7 and 2.0, respectively. Multiplying the number of moose seen by 2.0 and 3.7 gives an interval which may contain the estimated number of moose, if stratification is flown with conditions comparable to early winter surveys in Table 23. This relationship is not universal, and the percentage of moose seen on future stratification flights may be out of this range. As crude as these estimates may seem, they have proven valuable in areas where little was known about moose numbers. Most commonly these crude estimates have indicated that moose were more abundant than previ-

ously thought. Insufficient data exist to provide similar guidelines for late winter stratification if coniferous forest is present.

We recommend use of the stratification process in all areas where it can be applied and where quantitative information has not been collected. Using this approach, biologists can rapidly become acquainted with moose distribution and relative abundance in their areas of responsibility and gain new insights by collecting these data in a systematic manner.

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GLOSSARY

GREEK AND ARITHMETIC SYMBOLS

- α For confidence intervals: proportion of confidence intervals, from all possible samples and their estimates, that would not include the actual value (μ)
- For hypothesis testing: the acceptable probability of error if you were to conclude that a change in abundance had occurred when in fact it had not changed, i.e., a Type I error
- $1 - \alpha$ Specified probability for the confidence interval
- β The acceptable probability of error if you were to conclude that no change in abundance larger than the consequential difference had occurred when in fact it had changed, i.e., a Type II error
- β_0 Probability associated with t_0
- Δ_t Number of years between population size estimates
- $\hat{\Delta}_T$ Change in estimated population size
- ϵ_i Random sampling error for the i th estimate
- λ Finite rate of change in population size
- μ True value of parameter, e.g., number of animals or density
- ν Degrees of freedom
- ν^* Degrees of freedom for the population size estimate \hat{T}^* , which is based on combining two independent population estimates
- ν_e Degrees of freedom for the expanded population size estimate (\hat{T}_e)
- ν_{ei} Degrees of freedom for the total population size estimate (\hat{T}_i) in year i
- ν_{es} Degrees of freedom for the summed population size estimate (\hat{T}_s)
- ν_{ew} Degrees of freedom for the expanded estimate of moose in a sex-age class (\hat{W}_e)
- ν_g Degrees of freedom for the estimated linear rate of change in population size (\hat{g})
- ν_o Degrees of freedom for the observable population size estimate (\hat{T}_o)
- ν_{ow} Degrees of freedom for the estimated observable number of moose in a sex-age class (\hat{W}_o)
- ν_p Degrees of freedom for the estimated composition ratio (\hat{p})

- ν_r Degrees of freedom for the estimated exponential rate of change (\hat{r})
- ν_s Degrees of freedom for the observable sightability correction factor (SCF_o)
- ν_t Degrees of freedom associated with the test statistic, t'
- Σ Summation of the variable that follows Σ . The Σ has a subscript that corresponds to the subscript on the variable, e.g., $\Sigma_j x_j$ is the summation of numbers of moose in the j th sample unit where j = sample units 1 through n
- \cong Approximately equal to
- $>$ Greater than
- \geq Equal to or greater than
- $<$ Less than
- \leq Equal to or less than
- \wedge Indicates an estimate of the actual value when used as a cap above a symbol, e.g., \hat{T}
- $|$ The absolute value, e.g., $|5| = 5, |-5| = 5$

ROMAN SYMBOLS

- A_i Area (mi²) of the i th stratum
- CD The consequential difference of interest
- CI Confidence interval
- CL_u Upper confidence limit
- CL_l Lower confidence limit
- Cov() Covariance of the two variables in parentheses
- C_s Number of minutes required to fly an intensive search of a 2-mi² sightability plot
- C_r Number of minutes required to fly a regular search of a sample unit
- d As subscript, indicates the variable is in the denominator of a sex-age class ratio calculation, e.g., \hat{W}_{od}
- d_i Observable density (moose/mi²) in the i th stratum
- d_{iw} Observable density of moose in a sex-age class in the i th stratum
- e Base of the natural logarithm; a constant $\cong 2.71828$

g	Annual linear rate of change in population size	SU	Sample unit
\hat{g}	Estimated annual linear rate of change in population size	SCF	Total sightability correction factor, which is the product of $SCF_o \times SCF_c$
H_a	Alternate hypothesis	\overline{SCF}	Mean of two or more sightability correction factors
H_o	Null hypothesis	SCF_c	Constant sightability correction factor estimated from independent experimental work
i	Subscript denoting a specific member in a series, e.g., i commonly denotes the stratum as h (high), m (medium), or ℓ (low)	SCF_o	Observed sightability correction factor estimated from a low and high intensity search of selected plots
j	Subscript denoting a specific sample unit in a series of sample units, j = sample units 1 through n	t	Student's t -statistic
L_i	\log_e of the population estimate in year i , i.e., $\log_e \hat{T}_i$	t^o	Calculated t -statistic used for evaluating the probability of making a Type II error, β
n	Sample size	t'	Calculated t -statistic used for detecting significant differences between two population size estimates
n	As subscript, indicates the variable is in the numerator of a sex-age ratio	t_i	A variable representing time in years that is assigned to a population size estimate that is used for calculating rate of growth
n_i	Number of sample units surveyed in the i th stratum	\hat{T}	Total population size estimate (expanded population estimate \times constant sightability correction factor)
n_i^*	Optimum number of sample units that should be searched in the i th stratum	\hat{T}_c	Expanded population size estimate (observed population estimate \times observed sightability correction factor)
n_o	Number of 2-mi ² plots surveyed with an intensive search and used for estimating the observed sightability correction factor (SCF_o)	T_i	Actual population size in the i th year
n^o	Optimum number of sightability plots to be intensively searched	\hat{T}_i	Observable population size estimate in the i th stratum (all Sections except 3.12 and 4), or Estimated total population in the i th year (Sections 3.12 and 4)
N_i	Total number of sample units in the i th stratum	\hat{T}_o	Observable population size estimate for the entire survey area
\hat{p}	Estimated ratio between two sex-age classes	\hat{T}_s	The sum of two or more population size estimates from adjacent areas
\hat{r}	Observed exponential rate of population growth	\hat{T}^*	Population size estimated by combining two independent estimates of the same population
RVF_i	Relative variation factor of the i th stratum's observable moose estimate used for between strata allocation of sampling effort	u_k	Number of moose seen during the intensive search in the k th plot; $k = 1$ through n_o
RVF_i^o	Relative variation factor of the i th stratum's observable moose estimate used for allocating effort between sightability estimate and stratum i 's observable moose estimate	v_k	Number of moose seen during the standard search in the k th plot; $k = 1$ through n_o
RVF_s^o	Relative variation factor of the observed sightability correction factor (SCF_o) estimate for allocation of sampling effort between sightability estimate and individual strata observable moose estimate	$V()$	Sampling variance of the parameter in parentheses
s_q^2	Sample variance for estimate of population size. Subscripts added to s_q^2 indicate the specific sample variance, e.g., see s_{qi} below	w_j	Number of moose in a sex-age class observed in the j th sample unit
s_{qi}^2	Sample variance for the estimate of population size in the i th stratum	w_{jd}	Number of moose in the denominator sex-age class in the j th sample unit
s_{qiw}^2	Sample variance for a sex-age class in the i th stratum	w_{jn}	Number of moose in the numerator sex-age class in the j th sample unit

\hat{W}	Estimated number of moose in a sex-age class, i.e., the expanded estimate corrected for the constant sightability correction factor	\bar{x}	Mean of measurements in sample units
\hat{W}_e	The estimated observable number of moose expanded by the observed sightability correction factor	\bar{x}_i	Mean area (mi ²) of all sample units surveyed in the <i>i</i> th stratum
\hat{W}_i	Estimated number of observable moose in a sex-age class in the <i>i</i> th stratum	x_j	The measurement in the <i>j</i> th sample unit (Section 2, REVIEW OF SAMPLING ERROR AND PRECISION), or Number of mi ² in the <i>j</i> th sample unit (all sections other than Section 2)
\hat{W}_o	Estimated number of observable moose in a sex-age class in the survey area	y_j	Number of observed moose in the <i>j</i> th sample unit
\hat{W}_{od}	Estimated observable number of moose in the sex-age class in the denominator of a composition ratio		
\hat{W}_{on}	Estimated observable number of moose in the sex-age class in the numerator of a composition ratio		

TERMS

Population estimate—Estimated number of moose in a population

Population estimation survey—Survey to estimate numbers of moose in a population

Appendix 1.
Program Listings for the
Hewlett-Packard 97 Calculator

APPENDIX 1.

Program Listings for the Hewlett-Packard 97 Calculator

Listings of programs used in this manual allow you to program your HP 97 calculator. To enter programs, press keys in the order indicated by the sequential steps. Once entered, store programs on magnetic cards. Refer to your HP 97 Operators Manual for details on program entry and use.

Program 1. Estimation of population size (Section 3) and numbers in sex-age classes (Section 5). The same program is used for both types of calculations. The format for the listing is the sequential step number followed by the key instruction.

Card 1

001	*LBLA	046	RCL4	091	*LBL2	136	SPC	181	RCL9
002	CLRG	047	RCL6	092	RCL7	137	3	182	RCLI
003	P=S	048	x	093	RCL8	138	3	183	÷
004	CLRG	049	RCL9	094	RCLØ	139	3	184	CHS
005	1	050	PRTX	095	x	140	CHS	185	1
006	1	051	÷	096	2	141	RTN	186	+
007	1	052	CHS	097	x	142	*LBL E	187	x
008	CHS	053	RCL8	098	-	143	SPC	188	DSP3
009	DSPØ	054	+	099	RCL5	144	4	189	PRTX
010	RTN	055	STOA	100	RCLØ	145	4	190	ST+2
011	*LBLB	056	RCL4	101	X ²	146	4	191	X ²
012	Ø	057	X ²	102	x	147	CHS	192	RCL9
013	STO4	058	RCL9	103	+	148	DSPØ	193	1
014	STO5	059	÷	104	RCL9	149	R/S	194	-
015	STO6	060	RCL5	105	1	150	STOD	195	÷
016	STO7	061	-	106	-	151	DSP1	196	ST+3
017	STO8	062	RCLØ	107	÷	152	PRTX	197	SPC
018	STO9	063	x	108	RCL9	153	R/S	198	GTOE
019	P=S	064	RCLA	109	x	154	STOI	199	*LBLd
020	SPC	065	+	110	RCL4	155	DSPØ	200	SPC
021	*LBL1	066	RCL9	111	X ²	156	PRTX	201	RCL1
022	R/S	067	1	112	÷	157	SPC	202	DSP1
023	ENT↑	068	-	113	STOE	158	DSP1	203	PRTX
024	PRTX	069	÷	114	RTN	159	GTOB	204	STOD
025	R/S	070	RCL9	115	*LBLD	160	*LBLc	205	RCL2
026	PRTX	071	x	116	SPC	161	P=S	206	DSP2
027	Σ+	072	RCL4	117	2	162	SPC	207	PRTX
028	GTO1	073	X ²	118	2	163	RCL9	208	STOE
029	*LBLb	074	÷	119	2	164	DSPØ	209	X ²
030	SPC	075	RCLØ	120	CHS	165	PRTX	210	RCL3
031	R/S	076	+	121	DSPØ	166	RCL6	211	÷
032	ENT↑	077	STOØ	122	R/S	167	RCL4	212	.
033	PRTX	078	STOA	123	DSP2	168	÷	213	5
034	R/S	079	DSP6	124	PRTX	169	STOØ	214	+
035	PRTX	080	PRTX	125	STOA	170	DSP9	215	INT
036	Σ-	081	GSB2	126	R/S	171	PRTX	216	STOI
037	SPC	082	STOB	127	DSP6	172	RCLD	217	DSPØ
038	GTO1	083	PRTX	128	PRTX	173	x	218	PRTX
039	*LBLC	084	RCL9	129	STOB	174	DSP1	219	SPC
040	P=S	085	1	130	R/S	175	PRTX	220	5
041	SPC	086	-	131	DSPØ	176	ST+1	221	5
042	RCL6	087	STOC	132	PRTX	177	GSB2	222	5
043	RCL4	088	DSPØ	133	STOC	178	RCLD	223	CHS
044	÷	089	PRTX	134	*LBL3	179	X ²	224	RTN
045	STOØ	090	GTO3	135	DSPØ	180	x		

Card 2 (Program 1 continued)

001	*LBLA	044	R/S	087	5	130	.	173	RCL9
002	DSPØ	045	DSP2	088	2	131	9	174	÷
003	SPC	046	PRTX	089	4	132	6	175	RCL2
004	RCL1	047	STO6	090	STO1	133	STOØ	176	+
005	RCLA	048	RCL7	091	1	134	2	177	RCL9
006	x	049	x	092	.	135	.	178	÷
007	PRTX	050	DSPØ	093	4	136	3	179	RCL1
008	STO7	051	PRTX	094	2	137	7	180	+
009	RCL1	052	RCL6	095	1	138	2	181	RCL9
010	X ²	053	X ²	096	STO2	139	STO1	182	÷
011	RCLB	054	RCL8	097	.	140	2	183	RCLØ
012	x	055	x	098	9	141	.	184	+
013	RCLA	056	PRTX	099	8	142	8	185	*LBL9
014	X ²	057	SPC	100	3	143	2	186	RCL8
015	RCLB	058	*LBL3	101	STO3	144	3	187	√X
016	-	059	7	102	.	145	STO2	188	x
017	RCL2	060	7	103	4	146	2	189	STOØ
018	x	061	7	104	3	147	.	190	CHS
019	+	062	CHS	105	4	148	5	191	RCL7
020	PRTX	063	RTN	106	STO4	149	5	192	+
021	STO8	064	*LBLD	107	.	150	6	193	RCL6
022	Ø	065	9	108	2	151	STO3	194	x
023	RCLC	066	Ø	109	3	152	1	195	PRTX
024	X<Y?	067	PRTX	110	2	153	.	196	RCLØ
025	GTO1	068	1	111	STO5	154	5	197	RCL7
026	STO9	069	RCL9	112	GTO8	155	9	198	+
027	RCLI	070	X>Y?	113	*LBL E	156	STO4	199	RCL6
028	X<Y?	071	GTO5	114	9	157	1	200	x
029	STO9	072	6	115	5	158	.	201	PRTX
030	GTO2	073	.	116	PRTX	159	Ø	202	RCLØ
031	*LBL1	074	3	117	1	160	2	203	RCL7
032	RCLI	075	1	118	RCL9	161	STO5	204	÷
033	STO9	076	4	119	X>Y?	162	GTO8	205	1
034	*LBL2	077	GTO9	120	GTO6	163	*LBL8	206	Ø
035	RCL9	078	*LBL5	121	1	164	RCL5	207	Ø
036	PRTX	079	1	122	2	165	RCL9	208	x
037	SPC	080	.	123	.	166	÷	209	DSP1
038	SPC	081	6	124	7	167	RCL4	210	PRTX
039	*LBLB	082	4	125	Ø	168	+	211	SPC
040	6	083	5	126	6	169	RCL9	212	DSPØ
041	6	084	STOØ	127	GTO9	170	÷	213	GTO3
042	6	085	1	128	*LBL6	171	RCL3	214	R/S
043	CHS	086	.	129	1	172	+		

Program 2. Optimal allocation of sampling effort (Section 3). The format for the listing is the sequential step number followed by the key instructions.

Card 1

001 *LBLA	038 RCLC	075 \sqrt{X}	112 DSP9	149 -
002 CLRG	039 STO3	076 DSP9	113 PRTX	150 +
003 P=S	040 P=S	077 PRTX	114 RCL1	151 RCLØ
004 CLRG	041 GTO1	078 RTN	115 RCLE	152 +
005 *LBL1	042 *LBL2	079 *LBLE	116 x	153 RCL8
006 2	043 2	080 2	117 STO1	154 x
007 1	044 2	081 3	118 PRTX	155 STO9
008 1	045 2	082 3	119 RCL2	156 RCL4
009 CHS	046 CHS	083 CHS	120 RCLE	157 RCL5
010 DSPØ	047 SPC	084 SPC	121 x	158 +
011 RTN	048 R/S	085 R/S	122 STO2	159 RCL6
012 *LBLB	049 STOA	086 STOA	123 PRTX	160 +
013 GSB2	050 DSP3	087 DSP6	124 RCL3	161 RCL7
014 STO1	051 PRTX	088 PRTX	125 RCLE	162 x
015 P=S	052 R/S	089 R/S	126 x	163 ST+9
016 RCLB	053 GSB3	090 STOB	127 STO3	164 P=S
017 STO4	054 STOB	091 P=S	128 PRTX	165 DSPØ
018 RCLC	055 DSPØ	092 STOØ	129 SPC	166 2
019 STO1	056 PRTX	093 P=S	130 CLX	167 4
020 P=S	057 R/S	094 DSPØ	131 DSP1	168 4
021 GTO1	058 GSB3	095 PRTX	132 P=S	169 CHS
022 *LBLC	059 STOC	096 SPC	133 R/S	170 R/S
023 GSB2	060 PRTX	097 R/S	134 PRTX	171 *LBL3
024 STO2	061 CHS	098 STOD	135 STO7	172 .
025 P=S	062 RCLB	099 PRTX	136 R/S	173 5
026 RCLB	063 +	100 R/S	137 PRTX	174 +
027 STO5	064 X=Ø?	101 STOE	138 STO8	175 INT
028 RCLC	065 GTO4	102 DSP6	139 P=S	176 RTN
029 STO2	066 RCLB	103 PRTX	140 ÷	177 *LBL4
030 P=S	067 ÷	104 SPC	141 \sqrt{X}	178 1
031 GTO1	068 RCLC	105 RCLA	142 STxØ	179 DSP9
032 *LBLD	069 ÷	106 RCLB	143 P=S	180 PRTX
033 GSB2	070 1/X	107 x	144 RCL5	181 RTN
034 STO3	071 RCLA	108 \sqrt{X}	145 RCL2	182 R/S
035 P=S	072 x	109 RCLD	146 -	
036 RCLB	073 X=Ø?	110 x	147 RCL6	
037 STO6	074 GTO4	111 STOØ	148 RCL3	

Card 2 (Program 2 continued)

001	*LBLA	046	-	091	+	136	*LBL4	181	X>Ø?
002	2	047	+	092	STOE	137	SPC	182	GTO6
003	5	048	RCLØ	093	RCLB	138	RCL7	183	X=Ø?
004	5	049	+	094	RCLC	139	PRTX	184	GTO9
005	CHS	050	STOB	095	X<Y?	140	RCL8	185	1
006	DSPØ	051	RCL1	096	STOB	141	PRTX	186	ST-4
007	R/S	052	STOC	097	RCLB	142	RCL9	187	*LBL7
008	*LBLB	053	RCL4	098	GSB5	143	PRTX	188	.
009	RCL1	054	STOD	099	STOB	144	RCLB	189	1
010	STOA	055	P=S	100	RCL8	145	PRTX	190	ST+4
011	GTO1	056	RCL1	101	x	146	RCL1	191	GSB2
012	*LBLC	057	STOA	102	RCL7	147	PRTX	192	RCL5
013	RCL2	058	GSB3	103	P=S	148	RTN	193	RCL1
014	STOA	059	STO7	104	RCL6	149	*LBL5	194	-
015	GTO1	060	STO6	105	x	150	.	195	X>Ø?
016	*LBLD	061	P=S	106	+	151	5	196	GTO7
017	RCL3	062	RCL2	107	STOI	152	+	197	X=Ø?
018	STOA	063	STOC	108	RTN	153	INT	198	GTO9
019	GTO1	064	RCL5	109	*LBL3	154	RTN	199	.
020	*LBL1	065	STOD	110	RCLA	155	*LBLE	200	1
021	SPC	066	P=S	111	RCL4	156	SPC	201	ST-4
022	SPC	067	RCL2	112	x	157	SPC	202	*LBL8
023	2	068	STOA	113	RCL1	158	2	203	.
024	6	069	GSB3	114	÷	159	7	204	Ø
025	6	070	STO8	115	STOI	160	7	205	1
026	CHS	071	ST+6	116	RCLD	161	CHS	206	ST+4
027	R/S	072	P=S	117	X<Y?	162	R/S	207	GSB2
028	DSP4	073	RCL3	118	RTN	163	DSP1	208	RCL5
029	PRTX	074	STOC	119	RCL1	164	PRTX	209	RCL1
030	DSPØ	075	RCL6	120	RCLC	165	STO5	210	-
031	RCL1	076	STOD	121	X>Y?	166	DSPØ	211	X>Ø?
032	x	077	P=S	122	STOI	167	P=S	212	GTO8
033	RCLA	078	RCL3	123	RCL1	168	RCL9	213	X=Ø?
034	÷	079	STOA	124	RCLØ	169	P=S	214	GTO9
035	STO4	080	GSB3	125	x	170	X<Y?	215	.
036	GSB2	081	STO9	126	RCLA	171	STO5	216	Ø
037	GSB4	082	ST+6	127	÷	172	CLX	217	1
038	GTOA	083	RCLC	128	STOE	173	STO4	218	ST-4
039	*LBL2	084	-	129	RCLB	174	*LBL6	219	GSB2
040	P=S	085	RCL8	130	RLCE	175	1	220	*LBL9
041	RCL6	086	P=S	131	X<Y?	176	ST+4	221	GSB4
042	RCL3	087	RCL2	132	STOB	177	GSB2	222	GTOA
043	-	088	-	133	RCL1	178	RCL5	223	R/S
044	RCL5	089	+	134	GSB5	179	RCL1		
045	RCL2	090	RCLØ	135	RTN	180	-		

Program 3. Estimation of sex-age ratios (Section 5). The format for the listing is the sequential step number followed by the key instruction.

Card 1

001	*LBLA	046	x	091	PRTX	136	RCL9	181	3
002	CLRG	047	ST+8	092	RCLA	137	RCLE	182	3
003	P=S	048	RCLB	093	x	138	x	183	CHS
004	5	049	RCLC	094	DSP1	139	2	184	DSPØ
005	1	050	x	095	PRTX	140	x	185	RTN
006	1	051	ST+9	096	P=S	141	-	186	*LBLb
007	CHS	052	GTO1	097	ST+3	142	RCL6	187	DSP9
008	DSPØ	053	*LBLC	098	P=S	143	RCLE	188	R/S
009	RTN	054	SPC	099	RCL2	144	X ²	189	PRTX
010	*LBLB	055	5	100	RCL8	145	x	190	STOA
011	CLRG	056	2	101	RCLD	146	+	191	R/S
012	*LBL1	057	2	102	x	147	RCLC	192	PRTX
013	RCLØ	058	CHS	103	2	148	x	193	STOB
014	DSPØ	059	DSPØ	104	x	149	DSP3	194	R/S
015	SPC	060	R/S	105	-	150	PRTX	195	PRTX
016	R/S	061	DSP1	106	RCL6	151	P=S	196	STOC
017	PRTX	062	PRTX	107	RCLD	152	ST+6	197	1
018	STOA	063	STOA	108	X ²	153	X ²	198	ST-Ø
019	R/S	064	R/S	109	x	154	RCLI	199	RCLA
020	PRTX	065	DSPØ	110	+	155	÷	200	ST-1
021	STOB	066	PRTX	111	RCLC	156	ST+9	201	X ²
022	R/S	067	STOB	112	x	157	P=S	202	ST-2
023	DSP1	068	RCLØ	113	DSP3	158	RCL7	203	RCLB
024	PRTX	069	-	114	PRTX	159	RCL9	204	ST-3
025	STOC	070	RCLB	115	P=S	160	RCLD	205	X ²
026	1	071	÷	116	ST+5	161	x	206	ST-4
027	ST+Ø	072	RCLA	117	X ²	162	-	207	RCLC
028	RCLA	073	X ²	118	RCLI	163	RCL8	208	ST-5
029	ST+1	074	x	119	÷	164	RCLE	209	X ²
030	X ²	075	RCL5	120	ST+8	165	x	210	ST-6
031	ST+2	076	X ²	121	P=S	166	-	211	RCLA
032	RCLB	077	÷	122	RCL3	167	RCL6	212	RCLB
033	ST+3	078	RCLØ	123	RCL5	168	RCLD	213	x
034	X ²	079	x	124	÷	169	x	214	ST-7
035	ST+4	080	RCLØ	125	STOE	170	RCLE	215	RCLA
036	RCLC	081	1	126	DSP9	171	x	216	RCLC
037	ST+5	082	-	127	PRTX	172	+	217	x
038	X ²	083	STOI	128	RCLA	173	RCLC	218	ST-8
039	ST+6	084	÷	129	x	174	x	219	RCLB
040	RCLA	085	STOC	130	DSP1	175	PRTX	220	RCLC
041	RCLB	086	RCL1	131	PRTX	176	P=S	221	x
042	x	087	RCL5	132	P=S	177	ST+7	222	ST-9
043	ST+7	088	÷	133	ST+4	178	P=S	223	GTO1
044	RCLA	089	STOD	134	P=S	179	SPC	224	R/S
045	RCLC	090	DSP9	135	RCL4	180	5		

Card 2 (Program 3 continued)

001	*LBLA	046	X ²	091	GTO9	136	1	181	÷
002	P=S	047	÷	092	*LBL5	137	2	182	RCL8
003	SPC	048	+	093	1	138	.	183	+
004	RCL3	049	RCL7	094	.	139	7	184	RCL2
005	DSPØ	050	2	095	6	140	Ø	185	÷
006	PRTX	051	x	096	4	141	6	186	RCL7
007	RCL5	052	RCL3	097	5	142	GTO9	187	+
008	PRTX	053	÷	098	STO4	143	*LBL6	188	RCL2
009	X ²	054	RCL4	099	1	144	1	189	÷
010	RCL8	055	÷	100	.	145	.	190	RCL6
011	÷	056	-	101	5	146	9	191	+
012	.	057	RCLØ	102	2	147	6	192	RCL2
013	5	058	X ²	103	4	148	STO4	193	÷
014	+	059	x	104	STO5	149	2	194	RCL5
015	INT	060	STO1	105	1	150	.	195	+
016	STO8	061	PRTX	106	.	151	3	196	RCL2
017	PRTX	062	RCL8	107	4	152	7	197	÷
018	RCL4	063	STO2	108	2	153	2	198	RCL4
019	PRTX	064	RCL9	109	1	154	STO5	199	+
020	RCL6	065	X<Y?	110	STO6	155	2	200	*LBL9
021	PRTX	066	STO2	111	.	156	.	201	DSP9
022	X ²	067	RCL2	112	9	157	8	202	RCL1
023	RCL9	068	DSPØ	113	8	158	2	203	√X
024	÷	069	PRTX	114	3	159	3	204	x
025	.	070	*LBL3	115	STO7	160	STO6	205	STO3
026	5	071	5	116	.	161	2	206	CHS
027	+	072	4	117	4	162	.	207	RCLØ
028	INT	073	4	118	3	163	5	208	+
029	STO9	074	CHS	119	4	164	5	209	PRTX
030	PRTX	075	DSPØ	120	STO8	165	6	210	RCL3
031	RCL7	076	RTN	121	.	166	STO7	211	RCLØ
032	PRTX	077	*LBLD	122	2	167	1	212	+
033	SPC	078	SPC	123	3	168	.	213	PRTX
034	RCL3	079	9	124	2	169	5	214	RCL3
035	RCL4	080	Ø	125	STO9	170	9	215	RCLØ
036	÷	081	PRTX	126	GTO8	171	STO8	216	÷
037	STOØ	082	1	127	*LBL5	172	1	217	1
038	DSP9	083	RCL2	128	SPC	173	.	218	Ø
039	PRTX	084	X>Y?	129	9	174	Ø	219	Ø
040	RCL5	085	GTO5	130	5	175	2	220	x
041	RCL3	086	6	131	PRTX	176	STO9	221	DSP1
042	X ²	087	.	132	1	177	GTO8	222	PRTX
043	÷	088	3	133	RCL2	178	*LBL8	223	GTO3
044	RCL6	089	1	134	X>Y?	179	RCL9	224	R/S
045	RCL4	090	4	135	GTO6	180	RCL2		

Appendix 2.

Data Forms

APPENDIX 2.

Data Forms

Photocopy and use these forms until you develop ones meeting your specific needs.

Game Management Unit(s)

Subunit(s)

Date _____

Range of SU numbers

Stratum

Low

Medium

High

Other

[illegible][illegible][illegible][illegible]

Form 3. Moose survey data gathered during standard or intensive searches of sample units.

SU no. _____ Date _____ Page _____ of _____

Survey area _____

Pilot/obs. _____ Est. area _____ mi²

Type of search: Standard (e.g., 4-6 min/mi²) ☐
Intensive (e.g., 12 min/mi²) ☐

Dominant habitat _____

STANDARD SEARCH DATA SUMMARY

Strata H ☐ , M ☐ , L ☐ , O ☐

Total moose seen _____

Min. searched _____

Measured area (mi²) _____

Search effort (min/mi²) _____

Obs. density (moose/mi²) _____

INTENSIVE SEARCH DATA SUMMARY

No. moose std. search _____

No. moose int. search _____

Int. search time (min) _____

WEATHER: Clouds _____ Precipitation _____ Temperature _____ Wind _____ Turbulence _____

LIGHT		SNOW AGE AND COVER			SEARCH TIME
TYPE	INTENSITY	Fresh <input type="checkbox"/>	Complete <input type="checkbox"/>		
Bright <input type="checkbox"/>	High <input type="checkbox"/>	Moderate <input type="checkbox"/>	Some low veg. <input type="checkbox"/>		Stop time _____
Flat <input type="checkbox"/>	Med. <input type="checkbox"/>	Old <input type="checkbox"/>	showing <input type="checkbox"/>		Start time _____
	Low <input type="checkbox"/>		Bare ground showing <input type="checkbox"/>		

REMARKS

In SCF plot (✓)	Group no.	Bulls/Activ.			Cows and calves/Activ.				Unk. sex-age	Total moose	Habitat moose are in
		Yrlg	Med	Lge	♀	♀/1 calf	♀/2 calf	Lone calf			
	1										H LS TS D SS S L
	2										H LS TS D SS S L
	3										H LS TS D SS S L
	4										H LS TS D SS S L
	5										H LS TS D SS S L
	6										H LS TS D SS S L
	7										H LS TS D SS S L
	8										H LS TS D SS S L
	9										H LS TS D SS S L
	10										H LS TS D SS S L
	11										H LS TS D SS S L
	12										H LS TS D SS S L
	13										H LS TS D SS S L
	14										H LS TS D SS S L
Sex-age totals		Y=	M=	L=	♀=	♀= Ca=	♀= Ca=	Ca=	U=		= Total Moose

Game Management Unit(s)

Subunit (s)

Stratum

Stratum Area

 mi^2

Total SUs In Stratum

SU no.	Date searched	No. moose in SU	SU area (mi ²)	Search effort (min/mi ²)	SU density (moose/mi ²)	No. moose in SCF searches	
						Std.	Int.

[illegible]

Form 5. Moose population estimation survey--data summary.

Survey Area _____
 Game Management Unit(s) _____ Subunit(s) _____
 Date of Survey _____ Survey Supervisor _____

DATA SUMMARY FOR STRATUM

STRATUM POPULATION ESTIMATE	Low stratum	Medium stratum	High stratum
A_1 = area (mi^2)	_____	_____	_____
N_1 = total SUs	_____	_____	_____
n_1 = no. SUs searched	_____	_____	_____
\hat{d}_1 = obs. density	_____	_____	_____
\hat{T}_1 = est. no. moose (uncorrected)	_____	_____	_____
$V(\hat{T}_1)$ = variance of \hat{T}_1	_____	_____	_____

DATA SUMMARY FOR SURVEY AREA

SURVEY AREA INFORMATION	EXPANDED POPULATION ESTIMATE
Total area (mi^2) = _____	SCF_c = sight. correction constant = _____
Total No. SUs = _____	\hat{T}_e = expand. pop. est. ($\hat{T}_o \times SCF_c$) = _____
Total No. SUs searched = _____	$V(\hat{T}_e)$ = variance of \hat{T}_e = _____
OBSERVED POPULATION ESTIMATE	v_e = degrees of freedom = _____
\hat{T}_o = obs. pop. est. (uncorrected) = _____	TOTAL POPULATION ESTIMATE
$V(\hat{T}_o)$ = variance obs. est. = _____	\hat{T} = total pop. est. ($\hat{T}_e \times SCF_c$) = _____
v_o = degrees of freedom = _____	d = density = _____
SCF_o = obs. sight. correction factor = _____	90% CI as % of \hat{T} = _____
$V(SCF_o)$ = variance of SCF_o = _____	CL_u = upper confidence limit = _____
n_o = no. SCF plots searched = _____	CL_l = lower confidence limit = _____
v_s = degrees freedom of SCF_o = _____	SCF = sight. correct. factor ($SCF_o \times SCF_c$) = _____

Form 6. Daily aircraft charter expenses during a moose population estimation survey.

Survey Area

Game Management Unit(s)

Subunit(s)

	Date					
	/ /	/ /	/ /	/ /	/ /	/ /
Air taxi Hourly rate	No. hrs Cost	No. hrs Cost	No. hrs Cost	No. hrs Cost	No. hrs Cost	No. hrs Cost
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
_____	_____	_____	_____	_____	_____	_____
Daily costs						
Cumulative daily costs						

Form 8. Summary information of sample unit (SU) sex and age class data.

Survey Area _____ Date _____

Game Management Unit(s)	Subunit(s)
-------------------------	------------

Stratum	Stratum Area	mi ²	Total SUs in stratum
---------	--------------	-----------------	----------------------

$$\text{SCF}_0 \quad \underline{\hspace{2cm}} \quad V(\text{SCF}_0) \quad \underline{\hspace{2cm}} \quad V_s \quad \underline{\hspace{2cm}} \quad \text{SCF}_c \quad \underline{\hspace{2cm}}$$
[illegible]

BIOLOGICAL PAPERS OF THE UNIVERSITY OF ALASKA

**BEHAVIOR, MECHANICS AND
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CARIBOU IN
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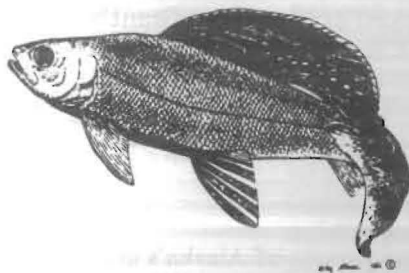
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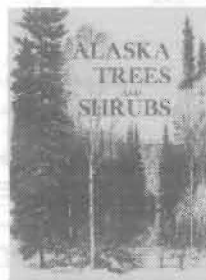
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